ASSESSING PATTERNS AND PROCESSES OF LANDSCAPE CHANGE IN OKEFENOKEE SWAMP, GEORGIA

By

CYNTHIA SMITH LOFTIN

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To my family: your love, patience, and encouragement made this work possible.

In memory of my friend, Millicent Quammen, who was an inspiration.

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Cynthia Smith Loftin

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Chairperson: Dr. Wiley M. Kitchens
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The Okefenokee Swamp is one of the largest freshwater wetlands in the world. Currently protected and managed as a national wilderness area and national wildlife refuge, the swamp has a history of human-caused manipulation and modification. The swamp landscape is dynamic; vegetation compositions and distributions continually change as the hydrologic environments change. These dynamics are driven by natural processes such as peat accumulation and wildfire, as well as the artificial manipulations of the recent past.

The Suwannee River sill was constructed following extensive wildfires during 1954-1955, with the intent of protecting the swamp and surrounding uplands from effects of wildfires. During subsequent years, concern was raised that the dam might be adversely affecting the swamp ecology by extending periods of inundation, increasing

water depths, and subsequently affecting swamp vegetation. Delineating the effects of the Suwannee River sill on the swamp hydrologic environment and vegetation distributions, in the process of exploring relationships among driving functions and landscape responses, was a purpose of this dissertation research.

Data collected at various spatial and temporal scales were examined to identify the sill's effects. A water level recorder network was spatially linked with a global positioning system survey, and the resultant topographic surface and hydrologic data were included in a grid-cell based hydrology model to track water movement throughout the swamp. Model simulations illustrated swamp water level fluctuations before and after the sill was in place, and predicted recent hydrologic history in the sill's absence, as well as sensitivities of swamp hydrology to altered evapotranspiration rates. Model simulations also predicted that the sill was affecting about 18% of the swamp area with increased inundation depths and durations, and vegetation change attributed to the sill was limited to this area.

Vegetation dynamics were also assessed at several scales, with remote sensing techniques, species-hydroperiod descriptions, and seed bank analysis and hydrologic manipulation. Current vegetation distributions are artifacts of historic logging and recent lack of fire, and also show sensitivity to local hydrologic environments. Inundation depth and hydroperiod create hydropatterns that influence species distributions. The swamp landscape is an expression of local dynamics, coupled with landscape-level processes such as fire, drought, and extensive historic logging occurring at multiple temporal scales.

CHAPTER 1
THE OKEFENOKEE SWAMP AND THE SUWANNEE RIVER SILL

The Okefenokee Swamp is a 200,000 ha freshwater wetland in Southeast Georgia and Northeast Florida. The landscape was relatively undisturbed by American explorers and settlers until the end of the nineteenth century, when it was subjected to draining, timber harvest, and mining. Protection and preservation of the landscape and remaining resources were goals in 1937, when the swamp became part of the National Wildlife Refuge system. The Suwannee River Sill, constructed in 1960 across the main outflow channel of the Suwannee River where it exited the swamp, was also intended to protect and preserve the swamp. Built in response to fires that burned across the swamp and into the surrounding landscape during 1954-1955, the sill was to impound water in the Okefenokee Swamp to keep similar fires from igniting and burning in the swamp. During the 30 years following construction of the sill, refuge managers, biologists, and the public exploring the swamp noticed changes in the composition and distributions of vegetation communities throughout the swamp. Were the changes indicating that the sill was affecting swamp vegetation, or was it undergoing natural successional processes? Concern for the health of the swamp ecosystem began to emerge. During 1989 the conditions of the sill gate structures were reviewed and found to be unstable, and in need of repair. Should the sill gates and impoundment berm be repaired, modified, or

destroyed? Was the Suwannee River Sill responsible for altering swamp vegetation, or were the perceived changes artifacts of the observers' temporal and spatial scales? Rather than "protecting" the swamp, was the sill damaging the wetland by disrupting the natural hydrologic environment and subsequently the vegetation community dynamics?

Addressing these questions presents an opportunity to examine the Okefenokee Swamp landscape composition and structure, and identify processes that create and maintain this structure. Hydrology is a primary driving function of all wetlands, and the hydrologic regime, principally hydroperiod, determines wetland type (Mitsch and Gosselink 1986). Many wetlands are also shaped by fire, and fire suppression may compromise wetland integrity (Mitsch and Gosselink 1986). In many wetland systems fire and the hydrologic regime are intricately linked; periodic droughts create conditions favorable for burning. Fires occur, potentially altering site environments (e.g., soil composition, site elevation, and hydrologic features), and subsequent species composition. Alterations of frequencies, intensities, and extent of these processes (fire and the hydrologic regime) can modify landscape composition and structure (DeAngelis and White 1994). Human activity has disrupted Okefenokee Swamp hydrology and fire regimes. Hierarchy theory suggests that the extent of these disruptions depends on the organizational level of the swamp ecosystem that is normally affected by these processes, and the relative importance of the affected driving function in maintenance of the system hierarchy.

The purposes of this work are to describe the spatial, hydrologic environment of the Okefenokee Swamp, to identify changes in vegetation community distributions since

the sill's construction and their probable causes, and to examine the swamp landscape structure and driving functions in the context of hierarchy and succession theories. To achieve these goals it was necessary to analyze the swamp vegetation and shaping functions from several spatial and temporal scales. Hydrologic monitoring and topographic surveying at locations throughout and surrounding the swamp provided data for describing the swamp hydrology. Remote sensing and ground truthing provided landscape-level vegetation distribution information. Transects across topographic gradients provided relational data among species occurrences, hydrologic features, and site conditions. Seed bank composition, source, and response to hydrologic regimes imposed in controlled greenhouse conditions suggested species germination sensitivities and potential responses to changing hydrologic conditions. Wildfire and prescribed burning records provided a spatial history of fire to compare with hydrologic and vegetation distribution information. Pre-logging surveys implied vegetation distributions resulting from natural successions, and logging records, historic aerial photography, and recent satellite imagery provided an indication of the extent and duration of logging impacts. A spatial hydrology model was used to estimate the spatial extent of the sill's influence on the swamp hydrologic environment. And, a geographical information system (GIS) was used to identify the spatial relationships of all of these components to the sill and to current vegetation community distributions and hydrologic features, elucidating the sill's effects on the swamp ecosystem.

This dissertation is arranged in 8 chapters. The first chapter discusses the application of theories of hierarchy, scale, and succession to dynamics in the wetland

landscape. A description of the Okefenokee Swamp ecosystem, history of human influence, and discussion of the history and intended purpose of the Suwannee River Sill are also contained in the chapter. Chapter 2 describes the acquisition and management of data included in development of the spatial hydrology model (precipitation, evapotranspiration, flow, and topography), vegetation distribution and species-hydroperiod associations (satellite image classification and accuracy assessment, aerial photography interpretation, and hydroperiod calculations), and precipitation and water level recorder network accuracy assessments. Swamp hydrologic conditions during the period, 1941-1995, are summarized in Chapter 2. Development, implementation, and assessment of a swamp hydrology model (HYDRO-MODEL) are detailed in Chapter 3. An assessment of the impact of the Suwannee River Sill on the swamp hydrologic environment based on the HYDRO-MODEL output is made in Chapter 3. Changes in vegetation community distributions since before logging occurred were detected with comparisons of pre-logging survey notes, post-logging aerial photography, and satellite imagery interpretations; these results are summarized in Chapter 4. Chapter 5 details the wildfire and prescribed burning history; interactions of fire history and swamp hydrology with vegetation changes are identified. Hydrologic environments associated with swamp vegetation species during 1962-1995 are described in Chapter 6, and seed bank composition and response to experimentally altered hydrology are detailed in Chapter 7. A synthesis of swamp vegetation succession in response to hydrologic alterations, logging, and wildfire management, and the role of these functions in shaping the swamp landscape is presented in Chapter 8.

This introductory chapter provides the theoretical basis of this wetland landscape analysis. First, the hierarchical structure of the components and processes of a landscape and the effect of observer scale on recognizing this organization are addressed. Thereafter, the processes that structure the wetland landscape (driving functions of fire and hydrology, and the "disturbances" they create), and the system's responses (perceived homogeneity and heterogeneity of the landscape, succession, and the resiliencies inherent in all systems) are discussed, as are techniques for studying landscape change (GIS, spatial modeling). Finally, a description of the Okefenokee Swamp environment, and a history of human impacts on the system are presented. The chapter concludes with a discussion of the Suwannee River Sill history and the primary questions directing this research.

Ecosystem Hierarchies and Scales

Landscapes are the expression of multitudes of components and processes interacting at varying temporal and spatial scales. A hierarchical arrangement of these components and processes is the framework of ecosystem organization (O'Neill et al. 1989a, 1989b). Ecosystem predictability and stability are dependent on preserving the processes and components occurring at multiple spatial and temporal scales that have resulted in the expressed system structure (O'Neill et al. 1989, O'Neill 1989, Holling 1987, 1986, Allen 1987, Urban et al. 1987, Allen and Starr 1982). Hierarchy theory (Allen and Starr 1982) recognizes nesting of system functions and properties with finer

scale. This nesting arrangement provides the framework in which an ecosystem is structured (Allen and Wyleto 1983). Interactions may occur among and within levels in the hierarchy, and the outcomes of these interactions may be predictable, until a disruption in the system's usual processes may lead to development of a system of different components. Eventually a new hierarchical framework develops, which may not contain the same components and may result in a different but stable system, components, and processes; a new stability domain develops, as the system reorganizes in response to these changes (Holling 1987, 1986, 1973). For example, each individual plant in a wetland cycles through a period of germination, growth, reproduction, and senescence, and many individuals are in various parts of this cycle at any time. An individual may live its entire life under a fairly constant, predictable environment. Some individuals and species in some years, however, will encounter limiting environments, such as extreme drought, which may eliminate them from the standing vegetation in the landscape. In the altered environment other species find the conditions suitable for their growth and survival. Thus, environmental modification (e.g.,long-term drought) can result in changes in species composition and changes driven by processes occurring at a scale and hierarchical level greater than the individual, i.e.,the wetland or the region. A new hierarchy results, with different species and environmental conditions, and possibly driven by different controlling functions. The original species may be present in the seed bank, however, and may again become part of the standing vegetation, given a return to conditions suitable for germination and maturation. The sustainable system depends on this type of adaptive cycle, whereby the system develops, becomes stable, undergoes

disruption, reorganizes, and has the potential to return to its original design or reorganize into another level in the hierarchy (Figure 1-1) (Holling 1987, 1986). A heterogeneous landscape indicates that a hierarchy of processes is operating at different spatial and temporal scales (O'Neill 1989). A connectivity among levels of the hierarchy that responds to variabilities of the systems' processes and components at various spatial extents is essential to the system's sustainability (Holling 1995, Allen and Wyleto 1983).

Stability perceived at the landscape level is a function of dynamics acting locally at a small scale, as well as at a greater extent. Thresholds exist whereby changes in the system components and processes disrupt the function of the system; these changes might be at any level of the system's hierarchy. The effect on the landscape could be innocuous, such as elimination of single individuals from a large population of great extent, or could result in the restructuring of the entire system by removing entire species or communities. A system's complexity is defined by the boundaries of the multiple levels and the interacting relationships among them. In general, large structures and low frequency processes occupy high levels of hierarchy and affect multiple layers of the system, whereas small structures and high frequency processes are low in the hierarchy and have limited effects (Ahl and Allen 1996). Predictability in the behavior of the system and recognition of the underlying, hierarchical model of the system's design and controlling processes result from observation at multiple levels of organization or scales (Ahl and Allen 1996).

The study of ecological processes requires selection of appropriate data resolution and extent. Perception and interpretation of the landscape, its patterns, driving

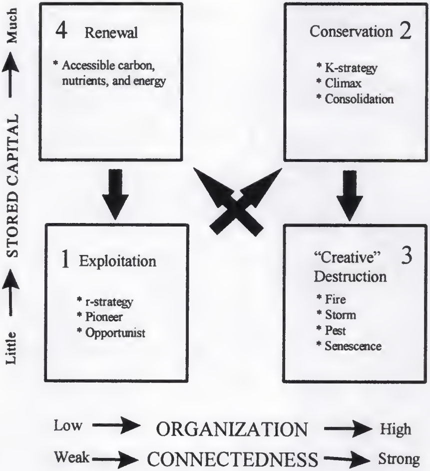


Figure 1-1. The four ecosystem functions and their relationships to the amount of stored capital and degree of connectedness, from Holling (1986).

processes, composition, and changes are dependent on the scale of observation (Holling 1992, O'Neill et al.1989a, 1989b, Forman and Godron 1986, Allen and Wyleto 1983) (Figure 1-2). For example, spatial scale is important to determining perceived effects of disturbance in a landscape; what appears as disruption at a local scale may actually be maintenance of the landscape mosaic at a regional scale (Risser 1991). Fire may maintain the landscape mosaic by changing the distributions of communities in landscape, but it may be a disturbance if it completely eliminates the potential return of the species in the landscape. Fine-scale measurement narrows scope and restricts extent; as data resolution becomes more coarse and extent increases, scope increases and the range of potential values for a particular landscape variable and its controlling processes also increase. The observer defines a measurement scale when the objectives are stated; a particular question posed by an observer defines the scale and hierarchy of interest. Selecting an inappropriate scale may lead to misinterpretation of patterns and driving processes. Identifying the appropriate data scale for detecting structure in a landscape and determining the processes that shape that landscape are fundamental to recognizing the landscape's hierarchical organization. Assessment of the effects of human-induced, landscape-level perturbations on a complex ecosystem requires integrating information from multiple disciplines and data resolutions. Analyses of system response to perturbations must address these interacting components, processes, and scales (Meentemeyer and Box 1987). Understanding how landscape pattern recognition correlates with scale facilitates compilation of information across scales (Farmer and

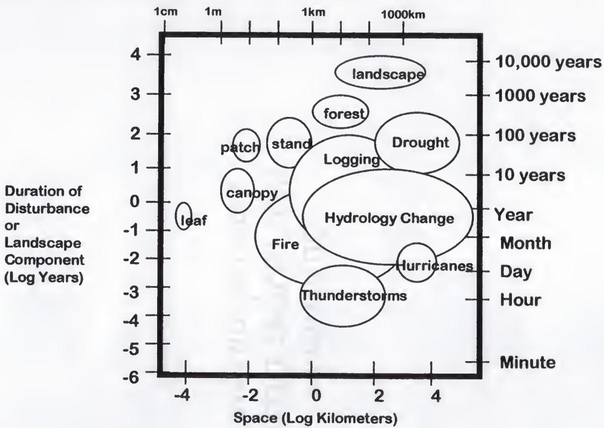


Figure 1-2. Interactions of temporal and spatial scales and the processes shaping a landscape and its components (adapted from Holling (1992)).

Adams 1991, Musick and Grover 1991). Viable management of an ecosystem ultimately depends on recognition of and continued interactions of these multiple-resolution components (Soule 1985).

Driving Functions

Spatial pattern in a landscape is the expression of interactions of current or historic processes and system components, and may determine the structure and function of the future landscape (Forman and Godron 1986). These determinant or controlling processes are the *driving functions* of the landscape. The dynamics of fire and hydrology in a wetland are driving functions that result in a shifting mosaic of communities across the landscape in various stages of succession, with current species composition reflecting a combination of inter- and intraspecific interactions and the recent driving environmental influence. Current compositions and distributions of communities in the landscape offer indications of the driving processes influencing the landscape in the past. Metastability (equilibrium) of the landscape may increase in the absence of disturbance (e.g.,fire), allowing the successional sequence to progress and requiring a greater degree of disturbance over time to disrupt the equilibrium (Forman and Godron 1986) (Figure 1-3). Distribution of species in the landscape, and knowledge of species' sensitivities to environmental conditions may elucidate the processes exerting greatest control on the landscape structure.

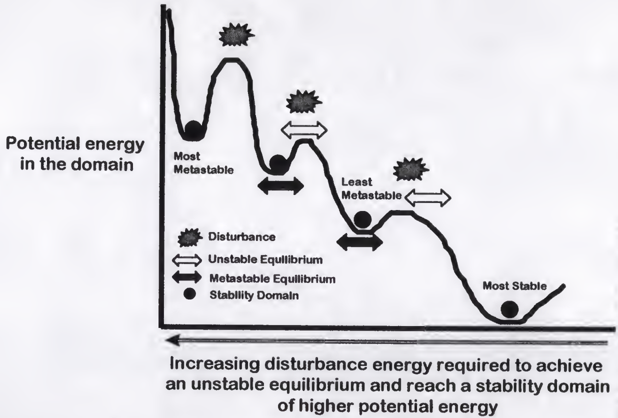


Figure 1-3. Interactions of disturbances and system potential energy levels leading to instability and restructuring (adapted from Forman and Godron (1986)).

Hydrology is a driving force in shaping the function and structure of wetlands. Hydrologic conditions such as water depth, flood duration and frequency, and water flow patterns influence both physical and biotic processes. Primary productivity, decomposition of plant material, nutrient cycling and availability, and vegetation composition are to some degree controlled by hydrology. Temporal constancy of a wetland's hydrology may be the dominant factor determining its biotic composition (Mitsch and Gosselink 1986). Increased flood duration may lower plant species richness as flood-intolerant species are eliminated, while decreased flooding or more frequent drawdowns may promote nutrient cycling, decomposition, and primary productivity.

Modifications of a wetland's hydrologic regime can alter the species composition, distribution, and productivity. Prediction of vegetation changes must consider relationships between hydrology and ecophysiology of individual species (Leck et al. 1989). Some plant species respond to flooding with inhibition of seed production and germination, retarded shoot, cambial, and root growth, arrested reproductive growth, and death. Wetland plants have mechanisms to acclimate to stresses of inundation, such as reduced gaseous exchange in a flooded environment. Formation of adventitious roots, aerenchyma tissue, hypertrophy of stem lenticels, secondary roots, and formation of knees or pneumatophores may be structural changes occurring in response to flood stress, to increase exchange of oxygen and waste products (Kozlowski 1984a, 1984b). A plant's age, duration of flooding, and the nature of the floodwater influence its response. If flooding persists species are replaced by flood-tolerant wetland species (Kozlowski 1984a, 1984b), usually resulting in a community with lower species diversity.

Elimination of flooded conditions may encourage return of the displaced species. Deuver (1988) and Duever et al. (1987) demonstrated that hydroperiod is a determinant of the distribution and composition of freshwater wetland communities in Florida. Disruptions in a wetland's hydrologic environment could lead to landscape-level structural changes in the wetland. Hydrology is a high-level controlling process in the wetland system hierarchy; its disruption could lead to a new hierarchical framework for the wetland system.

In addition to hydrology, fire is an environmental force that may shape a wetland over time. In southern stillwater swamps fire plays an important function in sculpting ecosystem structure (Ewel 1990). Occurrence of these fires is affected by seasonal cycling of hydrology and periodic droughts. During drier periods fires combust living and standing dead vegetation, litter, and normally saturated layers of peat. Although rapid community replacement might occur when mild fires leave many species alive to resprout, intense fires can eliminate all of the standing vegetation and possibly the peat. The seed bank in the exposed peat or sediment becomes the initial regenerative source, supplemented by seeds dispersed from adjacent sources. At this time species that can not germinate in inundated conditions can become established, provided the burned peat surface remains exposed. A similar response may occur when normally submerged substrate is exposed by drought. If new species establishing during dry periods are not tolerant of inundated conditions, they may be eliminated when water levels rise. With artificially extended inundation and limited fire disturbance, establishment of inundation-tolerant species occurs, slowly changing the local vegetation community

composition and structure and ultimately the landscape to a long-hydroperiod system. Intentional removal of fire while maintaining natural hydrologic processes can also restructure the landscape, by replacing fire-dependent species with those intolerant of fire.

Disturbances, Heterogeneity, and Succession

Changes in landscape structure may result from influences of the driving, functional processes that historically shaped the landscape. Changes may also reflect recent alterations in those processes that shape levels in the system's hierarchy. Whether changes in landscape structure and composition are perceived as disruptive to the system depends on the observer's scale, objectives, the type and intensity of the disturbance, and the system's evolution. A disturbance creates unsuitable conditions for some component of the system; its effects may be at various scales, favor some species and eliminate others, and may be essential in a system's maintenance. A *true disturbance* is a type of disruption absent from a system's evolutionary history (Rapport et al. 1985). Periodic fire and drought are driving processes in a wetland where species have evolved under their influence. The effects of fire and drought may not be disruptive to the system overall; the persistence of some species in the landscape may be dependent on occasional fire or drought to improve conditions for germination, remove competitors, or modify conditions that promote succession. Removal of these disturbances, which are driving functions in many wetlands (e.g.,fire or hydrologic cycling, such as drought-flooding

cycles), may be more detrimental to a species that evolved in a system maintained by periodic disruptions. For example where fire is removed, competitive advantage of fire-intolerant species may permit displacement of those dependant on fire. Artificially long hydroperiods and excessive water depths resulting from impoundment eliminate germination and reduce survival of species not adapted to those conditions. Unnatural disruptions on an ecosystem may affect biological diversity and processes with which the system evolved, which could ultimately damage the health of the system (Soule 1985). Ultimately, an altered stability domain is reached when a system's resilience to these perturbations is exceeded (Holling 1995, 1987, 1986).

Spatial heterogeneity in communities across a landscape reflects species sorting in a spatially diverse biotic and abiotic landscape (Milne 1991). Heterogeneity is scale-dependent; what appears heterogeneous at one scale is homogeneous at another (Meentemeyer and Box 1987). Landscape homogeneity may express a synergy of functions, which at a smaller scale appears to create heterogeneity (Meentemeyer and Box 1987). Although homogeneous landscapes are thought to enhance the spread of disturbance, heterogeneity may also exacerbate effects of disturbance by increasing exposure of the landscape interior through percolation (Risser 1991). Change in heterogeneity with spatial scale may reflect the functional organization of and shaping processes in the landscape (Musick and Grover 1991). A holistic approach to studying ecosystem responses recognizes that the effects of disturbance and change may occur over varying temporal and spatial scales, and differentially influence individual system components.

Environmental modification and changes in plant community distributions and composition in the landscape co-occur. The environmental change might be in response to stochastic events, such as fire or extreme weather, or caused by the landscape's occupants, such as peat accumulation, chemical soil modification, or shading. A suite of species will be adapted to the general conditions of the geographic region, i.e.,weather and geologic history will determine the potential species pool for the area. Which species are present in the standing vegetation will depend on the propagule source, competitive interactions among species, and environmental limitations of the site. While an individual occupies a site, it gradually modifies the site's characteristics, so that conditions become less suitable for itself and more favorable for other species. The site will undergo changes in species composition as the physical characteristics of the site are modified, eventually altering community structure and ultimately modifying the landscape. This change, or *succession,* in species composition driven by physiographic and biotic agents was first described in detail by Cowles (1911). Clements (1916) observed specific associations of species occurring in predictable sequences in colonization of a landscape; these *seral stages* terminated in a climax community specific to the system. He believed the climax community was an expression of the system, and not driven by changes caused by individual species. Disruption of the successional sequence by disturbance returned the entire species group, or sere, to an earlier seral stage, and the sequence of change would repeat. This idea was challenged by Gleason (1926) who recognized that a succession of species may occupy a site, but questioned that the sequence and association were predetermined by the system. He

believed that the expression of species at a site reflected the available propagule pool and variations of the environment, and could be altered by the species present, so that seemingly similar sites could be occupied by different individuals, species, and associations of species. Change in the composition of the site might occur, but he believed that it was not necessarily by predetermined associations of species; the response was of the individual, not the association. Gleason believed disturbance prohibited a true climax community from developing. Perhaps there is an acceptable compromise between these approaches. Succession is a phenomenon of the individual and species, not the community, and results from differential life histories, adaptations along environmental gradients, and competition among species. Change in an individual's environment that exceeds its tolerances may lead to occupation by other individuals and species. These changes operate at multiple spatial and temporal scales that may be complementary or independent. The selection of species that may occur is limited by adaptations to the environment; this gives the appearance of an association of species in a community type, but it is on individuals, not the group, that the environment exerts control.

Although disturbance might appear to disrupt an ecosystem, it can also be considered a driver of the succession continuum. Disturbance usually adjusts conditions to those earlier in the continuum; a cycle of disturbance, occupation, modification, development, and repeated disturbance develops. A system's response to the disturbance depends on the severity of the disruption and the degree of system complexity and development (Holling 1987, Allen and Wyleto 1983). Systems respond

to disturbance with a period of release and reorganization; a longer state of disequilibrium follows disturbance of later succession communities before reorganization occurs because more older systems may be less resilient to disturbance (Holling 1987). However, the succession sequence repeats in response to the disturbance, unless the system has been unnaturally altered. Disruptions in components and functions that the altered system experiences may prevent it from developing the same hierarchical structure; response of the system to disturbances may then be unpredictable and lead to an alternative stability domain (Holling 1987, Forman and Godron 1986).

Monitoring Landscape Change

Changes in plant communities as they occur within the landscape can be monitored using remote sensing and geographical information systems (GIS). Frequently, remote sensing provides historic data unavailable in any other format. Remote sensing provides data at various temporal and spatial scales at a cost lower than required by traditional field censusing techniques, which are used to validate interpretations of remotely sensed data with information at greater resolution. These data can be combined with other site features (e.g.,water chemistry, hydrologic parameters, topography, soil type) in a spatially referenced database. Estimation of missing data with interpolation may be necessary to provide complete spatial coverage, and data scale must be comparable among variables. Cartographic modeling techniques can be used with

these data to describe relationships among parameters and changes occurring, describe how landscape structure influences responses to perturbations, manipulate landscape features, and predict spatial effects of these manipulations at various scales (Turner and Gardner 1991). Limitations of the data and GIS techniques must be recognized, however, so that the influence of data and model scale on interpretations of results is understood (Haines-Young and Chopping 1996, Meentemyer and Box 1987).

The Okefenokee Swamp Ecosystem

The Okefenokee Swamp is a complex of forested uplands and freshwater wetlands covering approximately 1670 km^2 of lower Atlantic Coastal Plain in Ware, Clinch, Charlton, and Echols Counties, Georgia, and Baker County, Florida (Figure 1-4). Approximately 80% of the swamp is within the Okefenokee Swamp National Wildlife Refuge. The geologic origin of the swamp is debated; the traditional theory is that the swamp basin began to form during the Yarmouth Interglacial (200,000 years ago) when a coastal lagoon became separated from the Atlantic Ocean by a sand bar, known today as Trail Ridge (Carver et al. 1986, Cohen 1973b). During the thousands of years following this isolation, the seawater evaporated and organism remains and salts were removed by water and wind. Climatic changes occurring during the last glaciation brought increased precipitation, which collected in the lagoon basin and provided an environment suitable for freshwater wetland plants. Peat began to accumulate 6,500 years ago, as decay of plant remains was delayed by continuous flooding which created anaerobic, acidic

Figure 1-4. Location of the Okefenokee Swamp and Okefenokee Swamp National Wildlife Refuge.

conditions (Cohen 1973b). Peat accumulation continues today and is punctuated by periods of extreme drought, when peat is removed by fire and oxidation. An alternative theory initiates basin formation approximately 12,000 years ago; wind scoured the area, creating a depression where intercepted rainfall and surface runoff accumulated, and decreasing hydraulic head and outflow velocity increased retention time of standing water (Parrish 1971). Wetland plants eventually invaded, and the basin filled with accumulating peat (Rykiel and Parrish 1979, Rykiel 1977, Parrish 1971).

The swamp's watershed (3702 km^2) includes 3 drainage basins (Brook and Hyatt 1985, Hyatt 1984, Rykiel 1977). The Suwannee River carries 85% of the exiting flow from the western swamp; the St. Marys River (11%) and Cypress and Sweetwater Creeks (4%) account for the remainder exiting the southern third of the swamp (Rykiel 1977). Groundwater exchange is minimal (Brook and Hyatt 1985, Hyatt and Brook 1984). The Suwannee River sill was constructed in 1960 to intercept part of the Suwannee River discharge from the swamp; the low, earthen dam was intended to impound water in the swamp to protect it from drought, and to control the initiation and spread of wildfires within and beyond refuge borders (Chapter 742, Public Law 81-810, 70 Statute 668). Discharge from the swamp via the Suwannee River and variability of flow into the St. Marys River decreased during 1960-1986, following construction of the sill, whereas flow into the St. Marys River increased (Yin and Brook 1992b, Yin 1990). Water enters the swamp as precipitation (70%) and surface drainage of uplands along the western and eastern boundaries (Rykiel 1977). Water levels are generally lowest during April-May, when evapotranspiration demands are high and seasonal precipitation is low, and

October-November due to low precipitation (Chapter 2). Most rainfall occurs during June-September. During periods of normal hydrology, when peat is continuously saturated, swamp water depths average 0.7 m (Finn and Rykiel 1979). During the 25 years following construction of the Suwannee River sill, water depths levels during droughts were estimated to be 11 cm higher than during pre-sill droughts (Yin nd Brook 1992b, Yin 1990, Finn and Rykiel 1979).

Several vegetation communities occur in the Okefenokee Swamp. Prairies are found where peat layers are thick over depressions in the basement topography (Cohen et al. 1984, Cohen 1974, 1973a, 1973b) and cover approximately 8% of the swamp. Vegetation communities include shallow emergent prairies of yellow-eyed grass (*Xyris* spp.) and Walter's sedge (*Carex walteriana*) and deeper rooted or floating aquatic macrophytes (fragrant water lily, *Nymphaea odorata*, and golden club, *Orontium aquaticum*). Forested areas of pond cypress (*Taxodium acsendens*), titi (*Cyrilla racemiflora*), hurrahbush (*Lyonia lucida*), loblolly bay (*Gordonia lasianthus*), and dahoon holly (*Ilex cassine*) cover 57% of the swamp. Forested uplands of slash pine (*Pinus elliottii*), longleaf pine (*P. palustris*), saw-palmetto (*Serenoa repens*), and gallberry (*Ilex glabra*) occur on the remaining area of sandy islands and ridges (5%). Dense shrub thickets of titi, hurrahbush, and fetterbush (*Leucothoe racemosa*), covered with a blanket of bamboo greenbriar (*Smilax laurifolia*) and Walter's greenbriar (*S. walteri*) fill the remaining swamp interior (29%). Much of the western portion of the swamp, where mixed forests of pond cypress, loblolly bay, and blackgum (*Nyssa sylvatica* v. *biflora*) historically predominated, was logged during 1900-1930 (Izlar

1984). This area currently supports stands of shrubs and hardwoods, with little cypress regeneration (Hamilton 1984, 1982).

The classic model of hydrarch succession (development of a terrestrial forest climax community from an open water body) directed by autogenic processes (Mitsch and Gosselink 1986) is only partially applicable to the swamp. The topography facilitates collection of surface water in the swamp, and periodic droughts expose the accumulated peat, allowing oxidation and decline in the surface elevation. Site elevations are raised and hydroperiods altered when accumulated peat is not periodically exposed and oxidized, creating more favorable conditions for species less tolerant of flooding. However, in the swamp's history this exchange of species and apparent "progression" have frequently been disrupted when drought, fire, and subsequent species changes occur, and the wetland landscape mosaic is maintained (Hopkins 1947).

Palynological studies suggest that overall plant composition has been similar to the current species composition since peat layers began to accumulate (Cohen et al.1984, Rich 1984a, 1984b, 1979, Cohen 1975, 1974, 1973a, 1973b). However, spatial distribution of these communities has varied, as is indicated in peat deposits (Cohen et al.1984, Rich 1984a, 1984b, 1979, Cohen 1975, 1974, 1973a, 1973b). Hydrologic variations and fire interact to direct succession in the swamp (Roelle and Hamilton 1990, Hamilton 1984, 1982, Deuver and Riopelle 1984, Duever 1982, 1979, Rykiel 1977). Many species occurring in the swamp are adapted to nutrient-poor, saturated conditions. Okefenokee Swamp surface waters contain <1% of the system's nutrients; 59-98% of the Ca, Mg, Na, and K are found in the system's standing vegetation, and the remainder is

encumbered in slowly decomposing peat (Rykiel 1977). Exposure of the peat surface during drought hastens peat decomposition and bacterial cycling (Murray and Hodson 1985), making nutrients more available for use (Schoenberg and Oliver 1988, Bosserman 1983a, 1983b, Flebbe 1983), as do fires which may accompany extended drought. Most of the swamp has developed from open prairie to shrub bog to cypress or bay forest during some period of the past 6000 years, with undisturbed intervals varying from decades to hundreds of years. Drought, peat accumulation, and battery formation reduce the apparent water level, which permits succession of flood-intolerant woody species to occur. A progression from prairie to cypress swamp to broadleaved evergreen or mixed cypress swamp occurs in the absence of disturbance as peat accumulates (Hamilton 1984, 1982) (Figure 1-5).

As indicated by layers of charcoal in peat deposits, fire has checked succession in the swamp since peat began to accumulate thousands of years ago (Cohen et al. 1984, Cohen 1975, 1974, 1973a). Fire retards the progression of prairie to wooded swamp or returns the vegetation to and earlier stage. Certain vegetation communities such as cypress are frequently associated with concentrations of charcoal in the peat, suggesting a susceptibility to fire, especially during droughts (Cohen et al. 1984, Cohen 1975, 1974, 1973a). The central, deep-peat prairies have never been completely succeeded to cypress forest, possibly because they are topographic lows that have maintained conditions too saturated for forest species, or severe fire has burned the area frequently enough to retard expansion of woody species. Fires which burn the surface peat remove fire-intolerant plants but usually do not kill shrubs and large trees rooted in deep peat or sand beneath

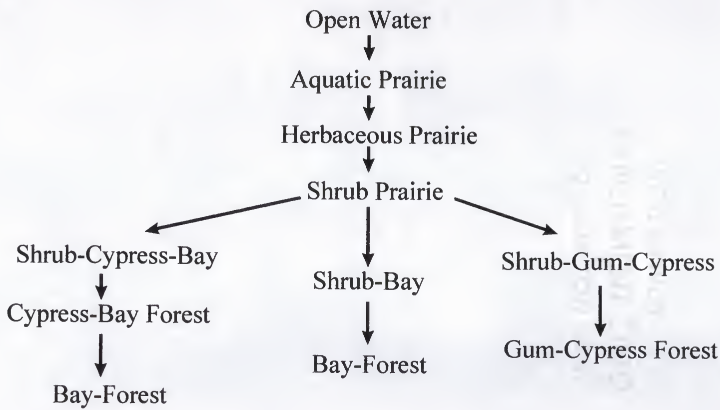


Figure 1-5. Hypothetical community changes occurring with peat accumulation in the absence of disturbance in Okefenokee Swamp (adapted from Hamilton (1982)).

shallow peat (Cypert 1973, 1961). More severe fires that burn to the deep, sub-peat sand layer are disjunct and rarely occur. Deep lakes occurring in the eastern swamp may have resulted from hot fires that burned through the accumulated peat and into the underlying sand. Prairies result when severe fires remove peat and woody root systems, preventing reestablishment of existing woody vegetation (Cypert 1973, 1961) due to lowered topographic surface and increased inundation depth. The light, surface fires which historically occurred frequently are probably more important than the infrequent, widespread, severe fires in maintaining the mosaic of existing vegetation associations (Roelle and Hamilton 1990). The manipulations of the swamp vegetation composition and hydrology during the past two centuries and current fire management have affected fire frequency and occurrence across the swamp (see Human Modification of Okefenokee Swamp section).

The Okefenokee Swamp landscape structure is affected by vegetation community succession. Swamp vegetation is determined by the hydrologic environment; disturbance history; species pool; propagule distribution and establishment requirements; potential longevity of propagules, juveniles, and adults; and, interactions of these features. Although species composition and abundance vary from site to site, there is a limited number of species occurring in the swamp, each with a certain range of life history requirements and environmental tolerances. Thus only a certain suite of species are likely to occur, and their presence in the landscape is mediated by inter- and intraspecific interactions, as well as other environmental processes. The swamp is maintained as a metastable equilibrium, where species are fluctuating between a competitive equilibrium

(maintaining the appearance of stability) and disequilibrium (species replacement), with intervening periods of changing communities in response to disturbance of greater intensity on a larger spatial scale. In the swamp's pre-modern (pre-1890) history this disturbance has been periods of drought and fire, creating a moving mosaic of vegetation communities in different stages of development in the landscape (Hamilton 1984, 1982, Rykiel 1977). Hydrologic alterations, logging, and changes in the burning regime are perturbations with the potential to disrupt development of this mosaic and affect future swamp structure.

Human Modification of Okefenokee Swamp

Humans have inhabited the Okefenokee Swamp for at least the past 4,000 years, and have lived in the Okefenokee Swamp area for 10-12,000 years (Trowell 1984a, 1984b), and have variously modified the swamp, particularly during the 20th century (Trowell 1994, 1989a, 1989b, 1988a, 1988b, 1987, 1984) (Table 1-1). The region's name is derived from a Seminole-Creek Nation word, *Oke-fin-o-cau*, meaning "land of the trembling earth" (McQueen and Mizell 1926), in reference to the floating islands found throughout the swamp. The swamp was surveyed by Mansfield Torrance in 1850 and many others in the following years, and was purchased from the State of Georgia by the Suwannee Canal Company in 1890 (Trowell 1994, 1989a, 1989b, 1988a, 1988b, 1984a, 1984b). The Suwannee Canal was excavated during 1890-1897 to drain the swamp to create an agricultural district; the effort failed, and in 1904 the land was

Table 1-1. Human-caused manipulations of Okefenokee Swamp vegetation and topography occurring during the past 150 years.

Type of Manipulation	When Manipulation Occurred	Probable Scale of Effect
Prescribed Burning, Arson	pre-settlement to present	local to swamp-wide
Dredging, Peat Mining	late 19th century to mid-20th century	local peat removal, regional hydrologic effect
Logging	late 19th century to mid-20th century	locally intensive, regionally scattered
Impoundment (Suwannee River sill)	1960-1962 construction, 1962 fully operational	local to regional effects depending on seasonal water levels
Boat Trail Cutting and Maintenance	20th century	local to regional effects on submerged, emergent, and nearby terrestrial vegetation

purchased by the Hebard Lumber Company. Marketable cypress, pine, and hardwoods were removed from the swamp and processed at local sawmills for shipment throughout the Southeast. Logging operations ceased in 1937 when the property was purchased by the United States government and added to the National Wildlife Refuge system. Peat mining in the Northeast swamp ceased in the 1950s, and the refuge was designated a national wilderness area in 1974 (Trowell 1989c, Fortson 1961).

During 1954-1955 the region experienced a severe drought and nearly 80% of the swamp was burned by wildfires (Hamilton 1984, 1982). Many of these fires began in the surrounding uplands, spread into the swamp where the peat slowly burned, and returned to the perimeter uplands. Neighboring landowners sustained significant property loss

from these fires. There was great interest in protecting the swamp and surrounding lands from future fires; a law (Appendix A) was enacted by the United States Congress in 1956 to require construction of a dam, the Suwannee River sill,

> to protect the natural features and the very substantial public values represented in the Okefenokee National Wildlife Refuge, Georgia, from disastrous fires..., and for the purpose of safeguarding the forest resources on more than four hundred thousand acres of adjoining lands recently damaged by wildfires originating in or sustained by the desiccated peat deposits in the Okefenokee Swamp. (Chapter 742, Public Law 81-810, 70 Statute 668, pages 781-782).

A perimeter road that would permit access to remote areas for fire control and serve as a fire break to spreading fires was also required by the law. In 1962 construction of the sill berm and closure of the 2 spillway gates were completed. The berm spans 7.2 km across the exiting flow of the Suwannee River and averages 35.5 m above mean sea level and 3-4 m above the surrounding Suwannee River floodplain; a ditch borders its entire length to the east. The original south gate collapsed in 1979 and was replaced; the north gate is the original structure. Although the gates are maneuverable, they remain closed to maximize the impoundment.

Apparent changes in vegetation composition of the Okefenokee Swamp during 1960-1990 precipitated concern that the Suwannee River sill and the Okefenokee National Wildlife Refuge fire management policy were permanently altering the swamp's ecology (Roelle and Hamilton 1990). Severe drought and fire have occurred in the Okefenokee Swamp at approximately 20-year intervals during the past 150 years (Cypert 1973, 1961). The Suwannee River sill was constructed to prevent recurrence of

fires during these droughts. During 1962-1990 extensive fires did not occur in the swamp. This may have been the result of the Refuge's fire management policy rather than the impoundment effects of the sill. Yin and Brook (1992b) and Yin (1990) found that the amount of water retained by the sill during severe drought (11 cm) was not enough to counteract an extreme drawdown (1-1.5 m during 1954-1955) due to drought. In fact, scattered fires during 1990 and 1993 suggest that the sill had not eliminated fire in that region. Thus, the sill was performing as it was intended (i.e.,to suppress fires) only in its localized area during periods of average hydrologic conditions, temporally and spatially extending hydroperiod beyond the local area during intervening years when water levels were generally higher (Roelle and Hamilton 1990), and not retaining a substantial amount of water during extended periods of below average rainfall.

Extending flooding by impounding runoff and stream flow may reduce water level variation that normally occurs with precipitation (Finn and Rykiel 1979). Finn and Rykiel (1979) compared pre- and with-sill water levels measured at the Camp Cornelia boat basin 29 km east of the sill, and reported an increase (10-13 cm) in average monthly water level after sill construction. Yin and Brook (1992b) and Yin (1990) measured an increase in average storage and a decrease in discharge. The higher water level behind the sill decreases the gradient approaching the sill, reducing flow and pooling the water (Finn and Rykiel 1979), especially during periods of above average rainfall. If the sill is extending periods of high water, it may be altering the landscape by affecting vegetation succession. Decreased fire frequency and extent may be encouraging woody vegetation to invade prairies during the occasional drier periods, hastening succession to cypress or

bay swamp, and eliminating the mosaic of vegetation and the associated biodiversity in a landscape historically perpetuated by periodic disturbances (Hamilton 1984, 1982).

When this study was initiated in late 1991, the Suwannee River sill had deteriorated since its construction and was in need of repair. The uncertainty of the sill's effects on the hydrology and vegetation of the swamp raised questions of whether the sill should be opened, repaired as a fixed height weir, or replaced with a controllable structure. Effects of the sill on vegetation communities within the landscape needed to be documented and predicted effects of future hydrologic management alternatives analyzed so that the refuge hydrology could be effectively managed. This dissertation research identifies the spatial extent of the Suwannee River sill's modification of swamp hydrology, and spatial changes in vegetation composition since the sill was constructed. Probable causes of the vegetation changes are proposed, and several hydrology management options and their effects on swamp vegetation composition are investigated. The following guiding questions are addressed in these dissertation chapters:

1) Have vegetation community distributions changed since the Suwannee River sill was constructed? If so, where have these changes occurred? Have fire frequency and distribution changed during this period?

2) Are swamp vegetation community composition and distribution correlated with hydroperiod and water depth?

3) What are the potential responses of the Okefenokee Swamp vegetation communities and landscape to future sill modification and hydrologic manipulation?

CHAPTER 2
DATA BASE ORIGIN AND DEVELOPMENT

Data Sources and Extent

Determining the effects of the Suwannee River Sill on the hydrology and vegetation of Okefenokee Swamp required diverse point and spatial data. The origin, management, and quality assessments of data used in the swamp hydrology model (see Chapter 3) and vegetation change analysis (see Chapter 4) are detailed in this chapter.

Precipitation, evapotranspiration, surface water inflow and outflow, water surface elevation, and water depth data are components of the swamp hydrology model. The hydrology model describes the swamp surface water environment during 1941-1993, the duration of the complete, concurrent weather and water level data. Summaries for Suwannee Canal Recreation Area (SCRA) and Stephen C. Foster State Park (SCFSP) include the complete period of record for these stations, 1941-1995. Historic, daily data were available for 1930-1991 from gauges monitoring some of the model parameters; additional data were collected during 1991-1995 from gauges installed in 1991-1992 to supplement the recorder network. Descriptive statistics for precipitation,

evapotranspiration, and surface water flow are calculated from the 1930-1995 data. Due to recorder discontinuity, malfunction, or removal, the daily records for these parameters during 1930-1995 were incomplete. Regression equations between correlated recorders estimated missing data to provide a more complete data record for the hydrology model. Descriptions of hydrology dataset management and the swamp hydrologic environment are discussed in the Swamp Water Level Data, Estimation of Missing Water Level Data, General Swamp Water Level Conditions, and the Suwannee River Sill's Effects on River Flow and SCRA and SCFSP Water Level Conditions sections of this chapter.

Swamp water level variation was monitored with daily data from a water level recorder network. Network design redundancies and discrepancies affect the accuracy of the water level estimates. Identifying the best design, to improve efficiency and accuracy of the recorder network for the intended purpose, is discussed in the Water Level Recorder Performance section of this chapter.

Most of the water in the swamp enters as direct precipitation (Yin and Brook 1992b, Yin 1990, Hyatt 1984, Blood 1981, Rykiel 1977). Estimations of spatial contributions of rainfall to the swamp water budget rely on data gathered at precipitation recorder stations. Accuracy of the recording network should be quantified so that the accuracy and limitations of the precipitation estimates can be identified. A rainfall variation and recorder network design analysis are discussed in the Precipitation Gauge Network Analysis section of this chapter.

Swamp topographic surface elevation is a component of the swamp hydrology model. Although 1994, 1:24,000 USGS topographic maps exist for the swamp region,

the data scale is insufficient for directing water movement across the slight gradient of the swamp at the hydrology model scale (500 x 500 m cell size). A more resolute topographic map was developed with a Global Positioning Systems (GPS) survey; this survey also permitted referencing the network of recorders to a common reference (elevation above mean sea level) and identifying their true location in the landscape within centimeters. The data collection and interpolation procedures used to create the swamp topographic surface map, and the development of swamp peat and sand surface profiles, are discussed in the Topography Map Development Section of this chapter.

A base map of current vegetation was needed to identify changes in vegetation community composition and distribution occurring in the landscape since the sill was constructed. SPOT multispectral and panchromatic satellite imagery were used to produce this base map; changes in swamp vegetation community distributions were identified by comparing maps created from interpretations of aerial photographs of the swamp taken in 1952 (7 years pre-sill) to those from 1977 (15 years with-sill) and the 1990 (28 years with-sill) base map. The procedures and accuracy of the satellite imagery classification are detailed in the Satellite Imagery Classification and Accuracy Assessment section of this chapter. Details of the photointerpretation and change assessment procedures are included in Chapter 4.

Swamp Water Level Data

Swamp water level data were compiled from several sources. The longest duration records were from staff gauges installed in Billy's Lake (at SCFSP) and the

SCRA boat basin during 1941; readings were made several times monthly at both stations until 1950, when daily readings were begun at SCRA. Daily readings were not made at SCFSP until 1968. Steven's chart recorders with float gauges were installed at SCRA in 1979 and SCFSP in 1980. Chart recorders were also installed at 11 other sites in 1979-1980 (Figure 2-1). Elevations of these recorders were referenced to staff gauges installed on site, and the reference elevation was transit-surveyed to perimeter USGS benchmarks during the early 1980s. During 1980-1991, 3 recorders were removed from the network, and those that remained were not regularly maintained, resulting in an incomplete record of daily water surface elevation. In 1992 the gauging network was examined, broken gauges were repaired, and an additional 13 gauges (Omnidata, Inc. digital recorders with Delta pressure transducers and WaterMark reference staff gauges) were installed throughout the swamp (Figure 2-1). Elevation of the reference staff at each recording station was related to a permanently established benchmark located within 500 m of the recorder. Location and elevation of these benchmarks were surveyed (see discussion of topography map development in this chapter) relative to Universal Transverse Mercator (UTM) zone 17 grid X and Y location and NAVD27 elevation projection of mean sea level, so that water surface measurements could be compared spatially. The digital gauges recorded water elevation once daily (hourly readings averaged every 24 hours); data were retrieved from the recorders every 4-6 weeks during 1992-1995. Daily water surface elevation recorded on the accumulated historic charts (1980-1991) and those retrieved quarterly from chart recorders during 1992-1995 were digitized and corrected to the reference benchmark elevation. Records from each station

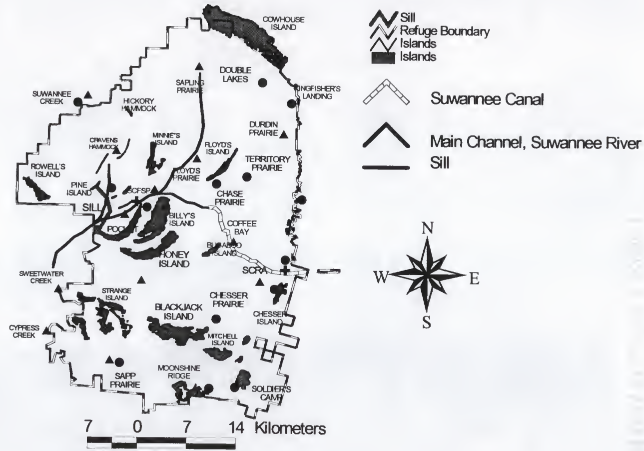


Figure 2-1. Water level and precipitation recorder locations in the Okefenokee Swamp during 1941-1995.

were compiled into spreadsheets; intervals of missing data were identified and correlations among recorders examined to identify regression equations to use in missing data estimation (see Recorder Correlations and Missing Data Estimation).

Water Level Recorder Performance

There were 26 gauges recording water elevation continuously or daily during 1979-1995 for varying lengths of time. Elevation of reference staffs above mean sea level, corrections to historic reference staff data, period of record, and days in operation are indicated in Table 2-1. The interpreted data from each recorder and staff during the periods of operation are illustrated in Figure 2-2. Estimated missing data are included in the plots to approximate a complete record for 1941-1995. Water level data were estimated for all recorder stations from SCRA and SCFSP staff data during 1941-1979. Estimates were calculated for 1-80% of the station water level data for 1980-1995; descriptive statistics of each station's record are listed in Table 2-2.

During 1992-1995 when the water level recorder network density was highest, 23 gauges were working for 20-99% of the interval (Table 2-3). In most cases recorder malfunction could be attributed to mechanical failure due to interference by wildlife or refuge visitors, or due to insufficient maintenance of recording equipment. During 1992-1995 digital recorders were most reliable, although one chart recorder operated for 91% of the interval. The poorer performance of chart recorders can be attributed to their age. Most of the stations had been deployed since early 1980. Solar rechargeable batteries caused problems with 3 digital units, and insufficient charges on non-rechargeable batteries were responsible for missing data on other units. Over the 694-5672 days of

Table 2-1. Water level recorder elevations and staff corrections, operating period, and precipitation gauge locations.

Station	Type[a]	Start Date	End Date	Staff Correction (m)	Ground Elevation Above Mean Sea Level at Staff (m)
Sill (Brown Trail)	chart, wl, p	2-1-1980	6-7-1995	+34.75	34.03
Chase Prairie	chart, wl, p	5-6-1980	4-10-1995	+32.24	36.21
Territory Prairie	chart, wl, p	5-6-1980	3-13-1995	+30.32	36.66
SCFSP	chart, wl, p	2-1-1980	2-22-1995	-0.009	34.12
SCRA	chart, wl, p	9-1-1979	7-3-1995	+36.14	36.08
Double Lakes	chart, wl, p	5-21-1980	2-22-1995	+36.18	37.35
Gannett Lake	chart, wl, p	6-4-1980	1-19-1995	-0.63	36.53
Seagrove Lake	chart, wl, p	12-5-1979	2-16-1995	+31.11	36.50
Moonshine Ridge	chart, wl, p	3-5-1982	5-16-1994	-1.13	35.62
Suwannee Creek	chart, wl, p	5-22-1980	10-17-1982	+35.97	36.02
Soldier's Camp	chart, wl, p	4-11-1980	3-5-1982	+33.83	34.0
Sapp Prairie	chart, wl, p	4-18-1980	3-9-1988	+35.97	35.20
Kingfisher Landing	chart, wl, p	1-11-1980	6-14-1995	+37.38	36.54
Coffee Bay	digital, wl, p	4-1-1992	6-14-1995	+35.77	36.69
Billy's Lake	digital, wl	4-16-1992	6-13-1995	+33.58	33.6
Suwannee River	digital, wl	5-7-1992	5-31-1995	+33.77	33.62
Sweetwater Creek	digital, wl	4-2-1992	6-1-1995	+33.84	34.04
Cypress Creek	digital, wl	4-3-1992	6-1-1995	+32.94	33.95
Floyd's Prairie	digital, wl, p	4-2-1992	6-1-1995	+34.86	35.27
Suwannee Creek	digital, wl	4-17-1992	7-20-1995	+36.66	36.02

Station	Type[a]	Start Date	End Date	Staff Correction (m)	Ground Elevation Above Mean Sea Level at Staff (m)
Sapling Prairie	digital, wl, p	2-4-1993	2-22-1995	+36.35	36.61
Durdin Prairie	digital, wl, p	4-1-1992	6-14-1995	+36.68	36.98
Honey Prairie	digital, wl, p	6-16-1992	12-15-1994	+35.84	36.11
Chesser Prairie	digital, wl	2-4-1993	6-14-1995	+35.94	35.68
Sapp Prairie	digital, wl, p	2-4-1993	12-15-1994	+35.70	35.20
Craven's Hammock	digital, wl, p	4-1-1992	5-31-1995	+34.95	35.15
SCFSP	staff, wl	1-4-1941	2-22-1995	-0.009	34.12
SCRA	staff, wl	1-4-1941	7-3-1995	+36.14	36.08

[a] Data are recorded daily by automated (chart, digital) systems or refuge personnel (staff), and stations monitor daily water surface elevations (wl), precipitation (p), or both.

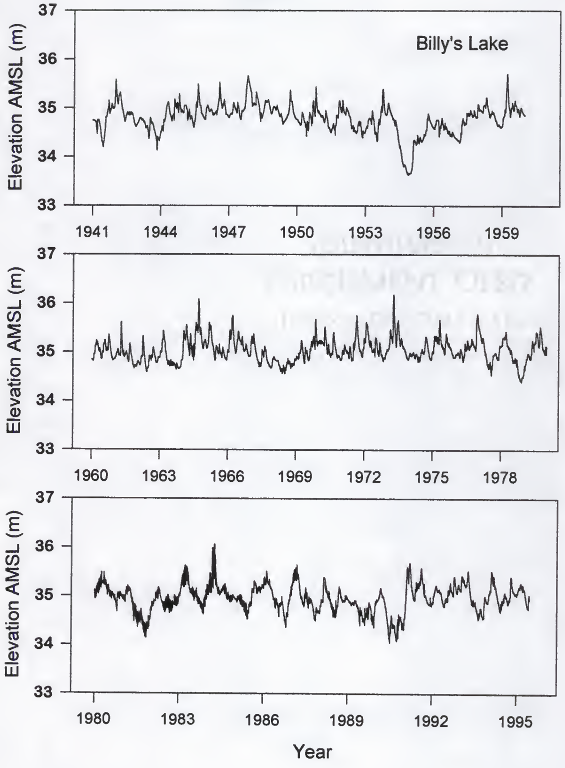
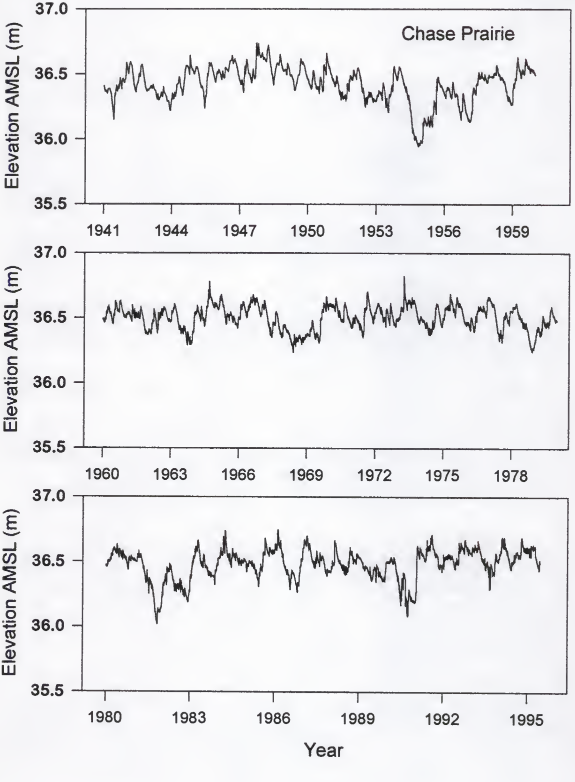


Figure 2-2. Daily water surface elevation above mean sea level (AMSL) during 1941-May 1995 recorded at locations in Okefenokee National Wildlife Refuge, GA.



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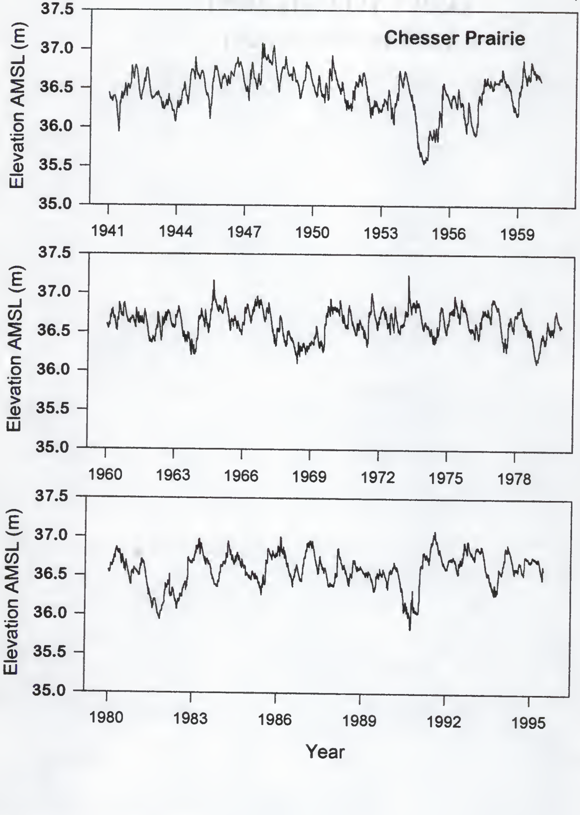

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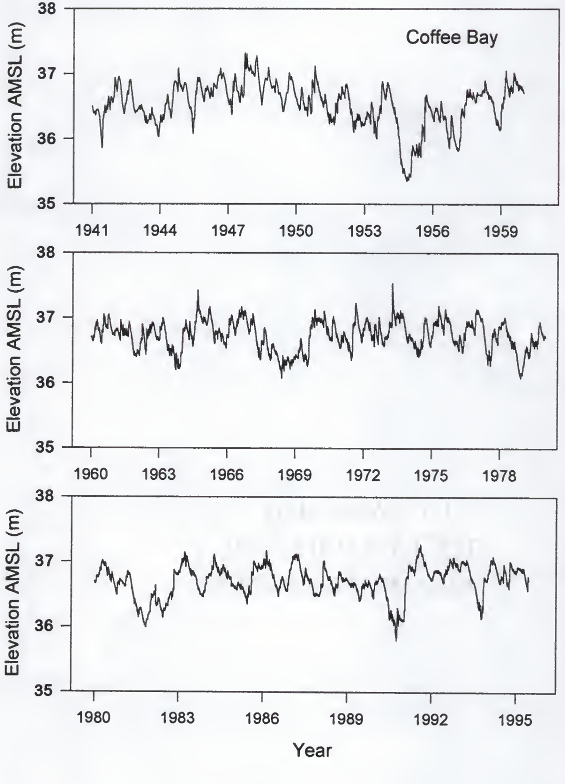

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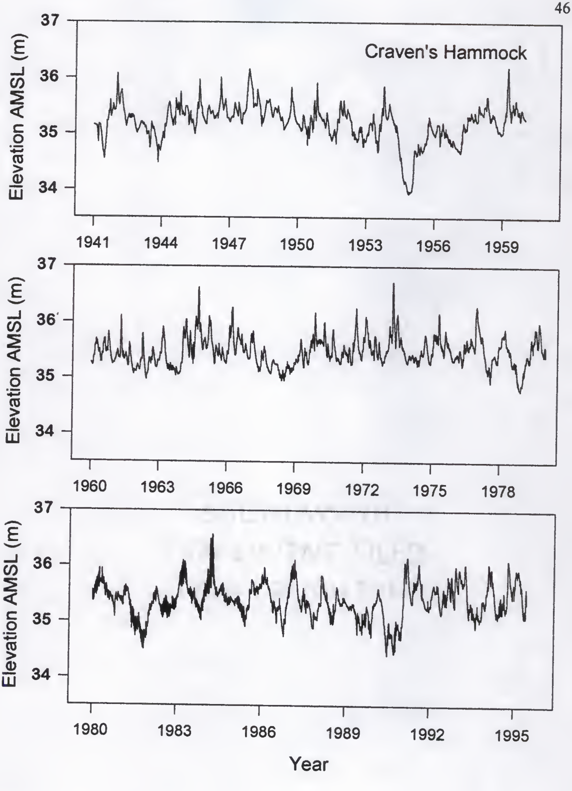

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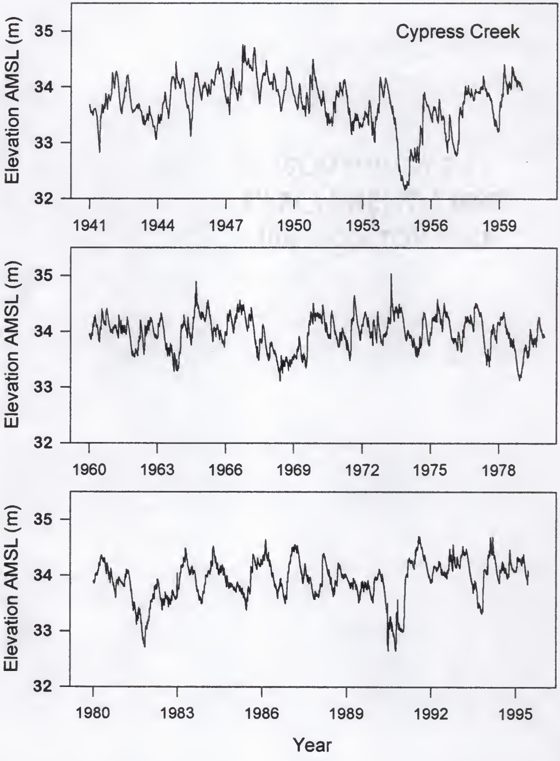

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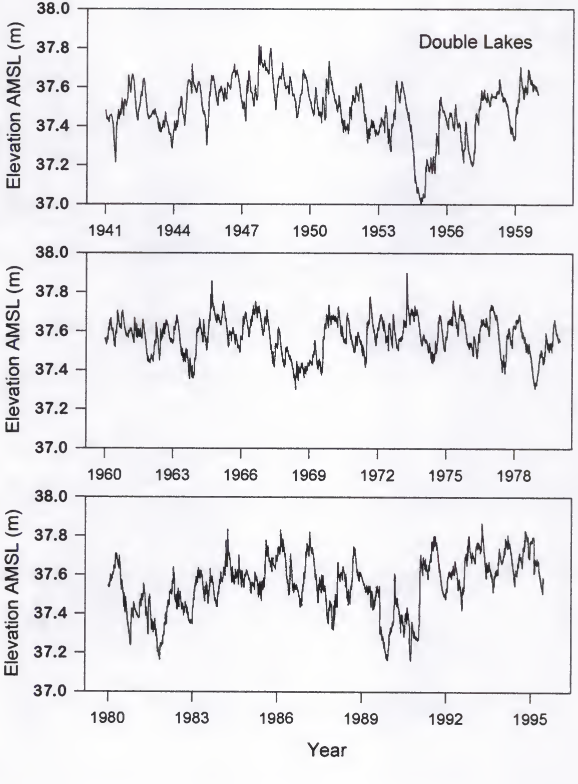

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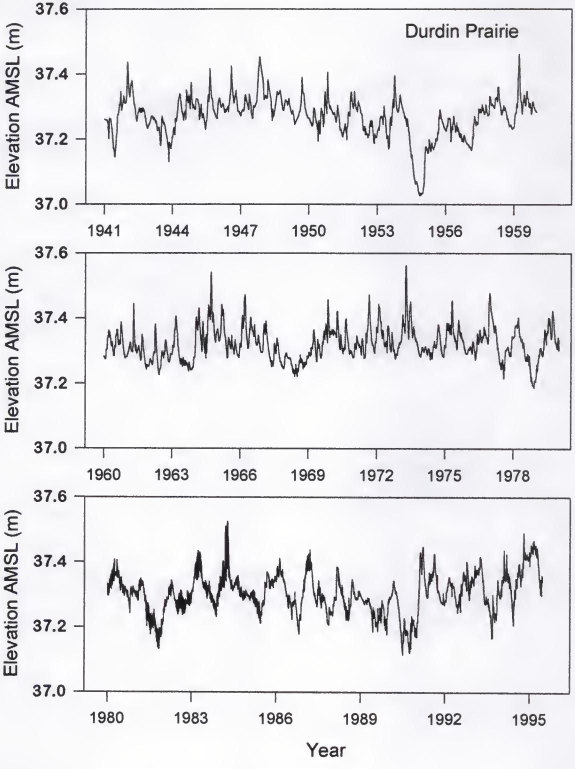

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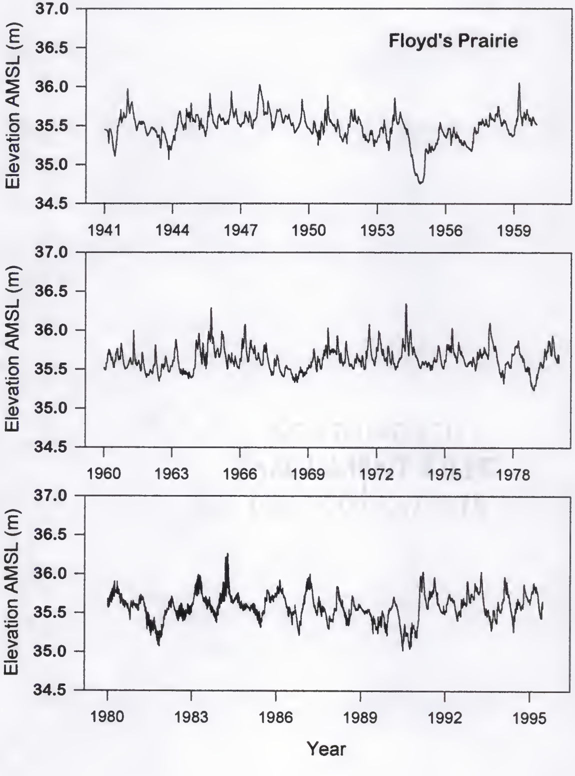

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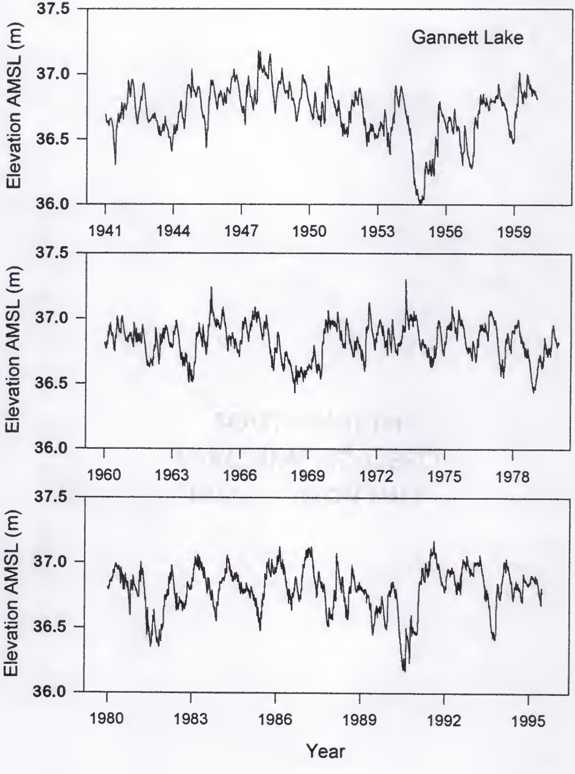

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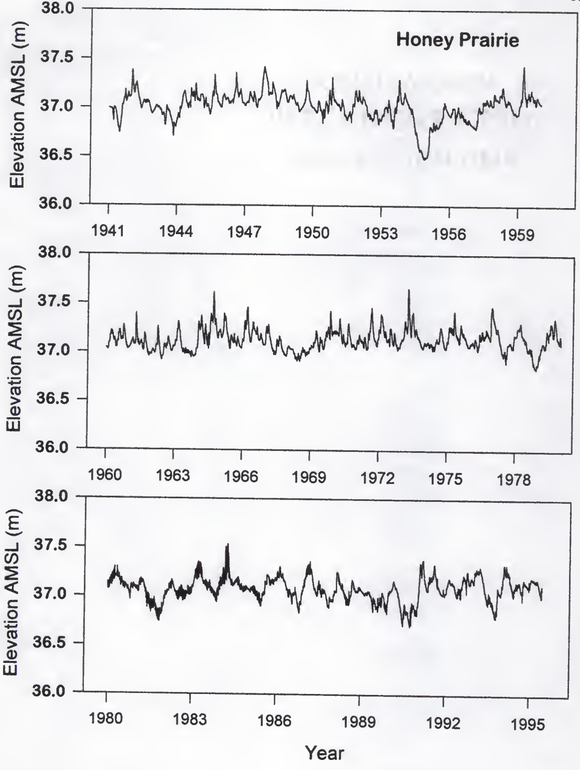

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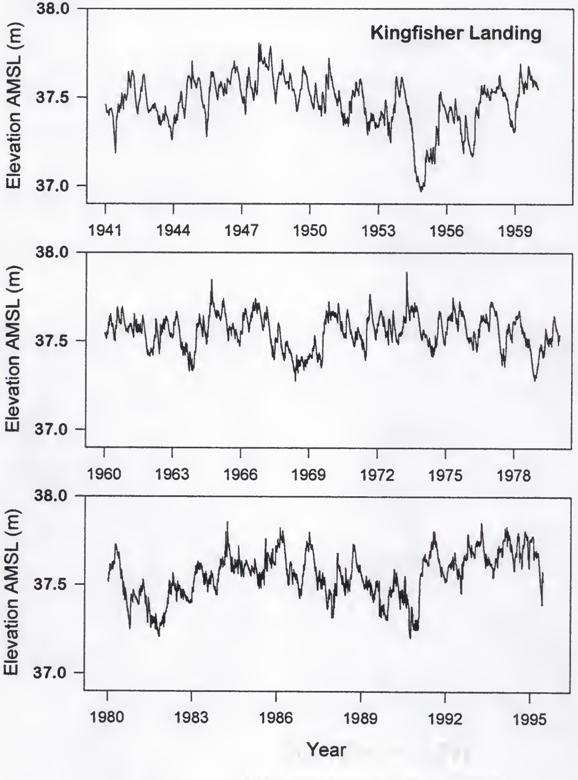

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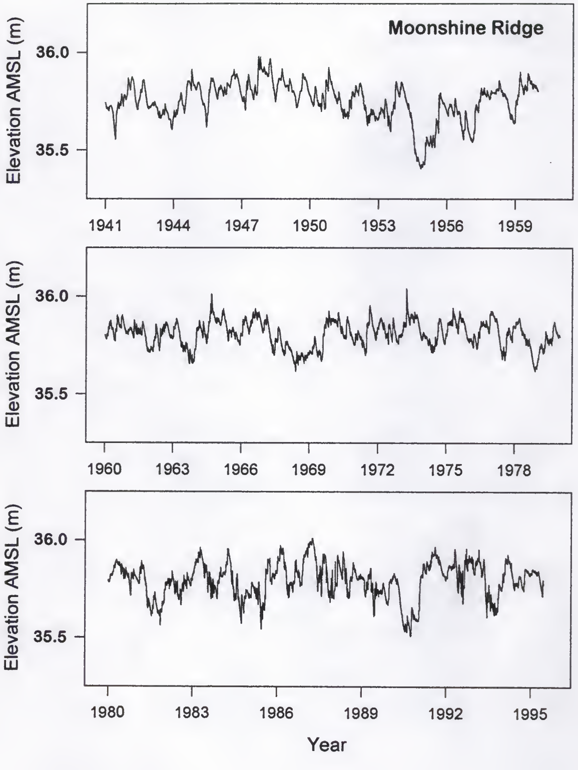


Figure 2-2--continued.

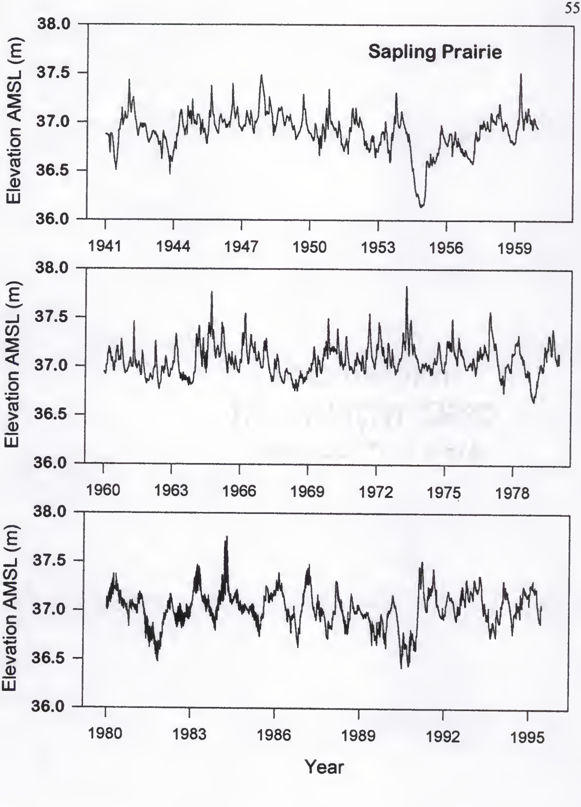


Figure 2-2--continued.

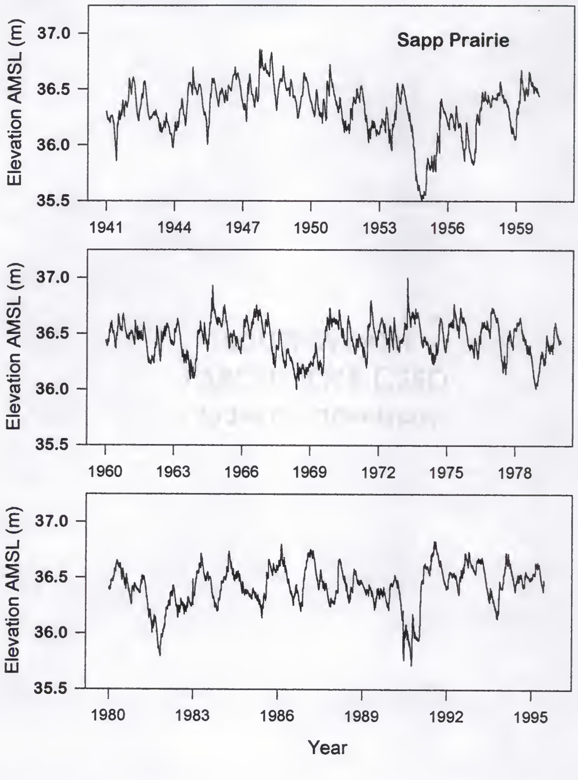


Figure 2-2--continued.

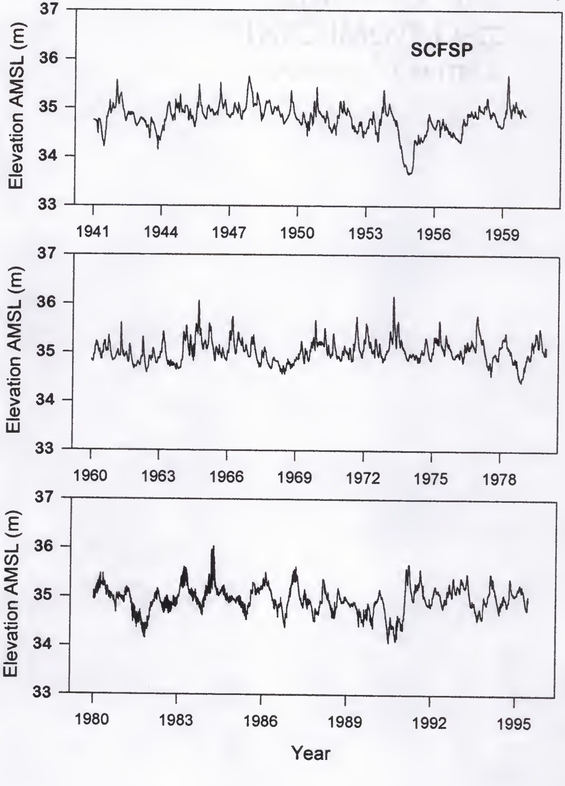


Figure 2-2--continued.

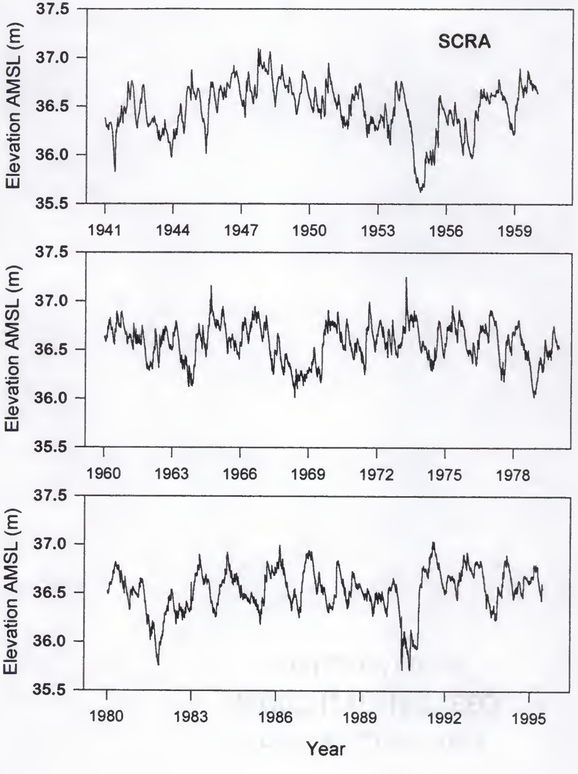


Figure 2-2--continued.

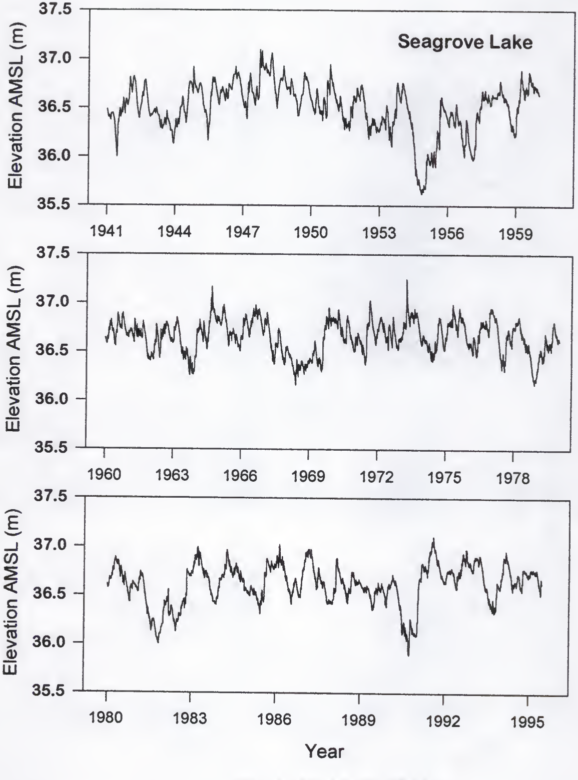


Figure 2-2--continued.

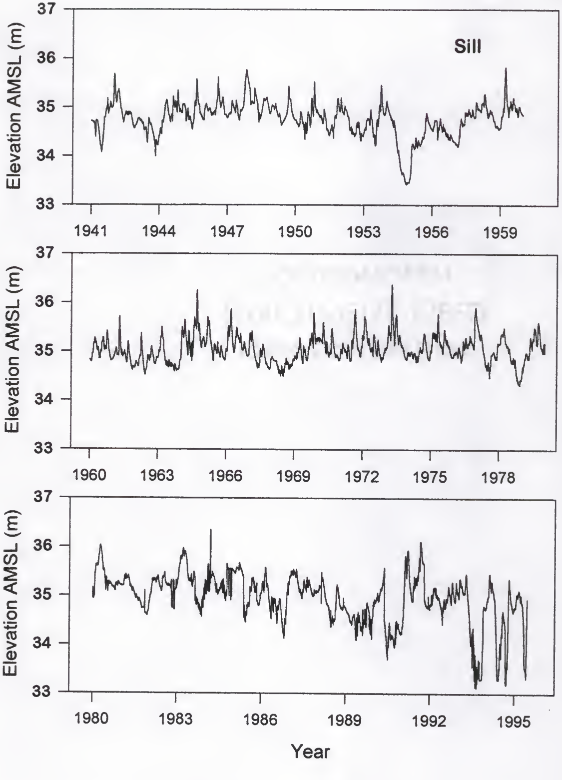


Figure 2-2--continued.

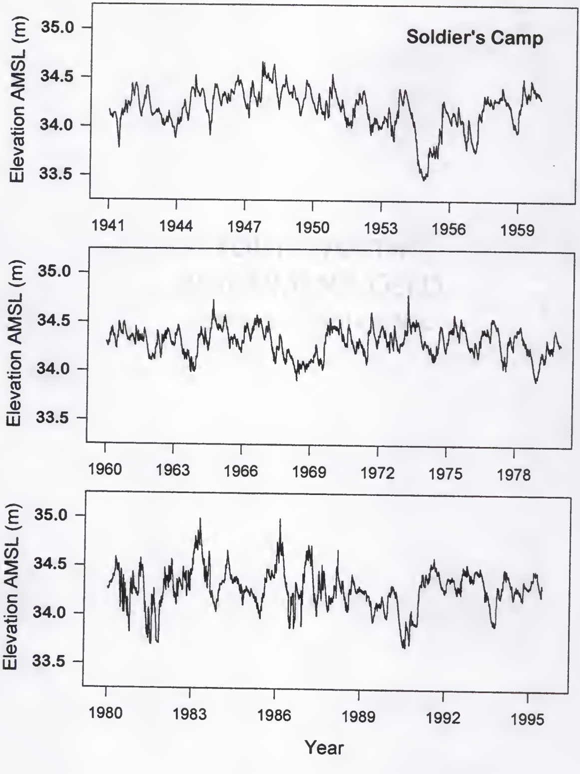


Figure 2-2--continued.

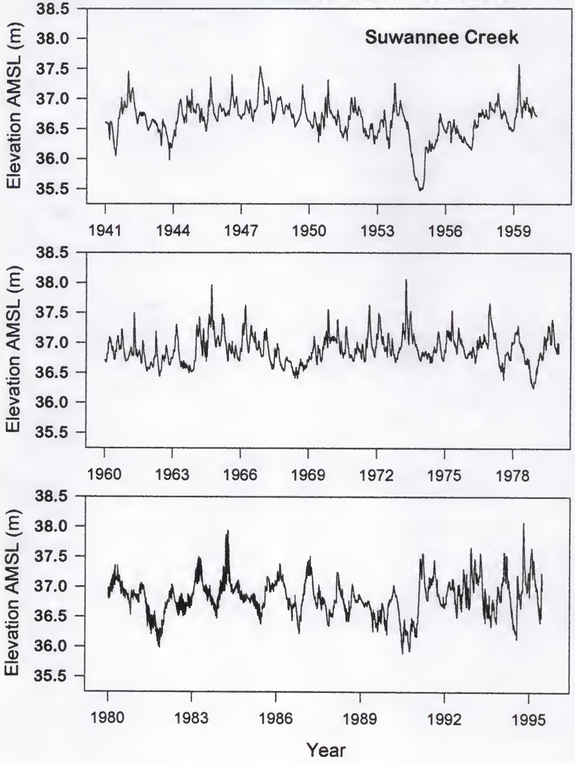


Figure 2-2--continued.

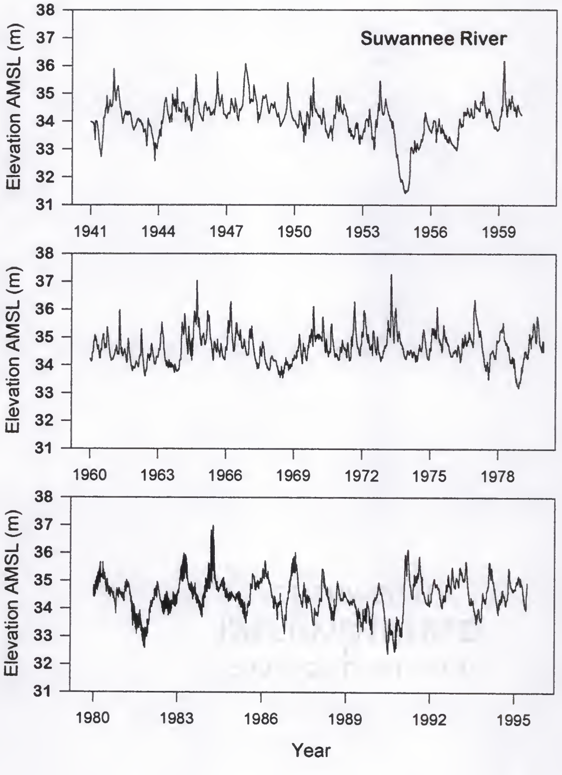


Figure 2-2--continued.

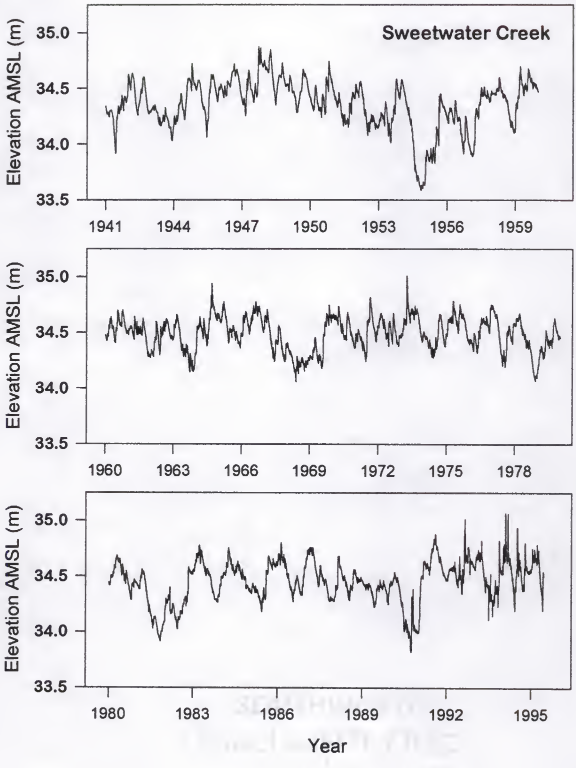


Figure 2-2--continued.

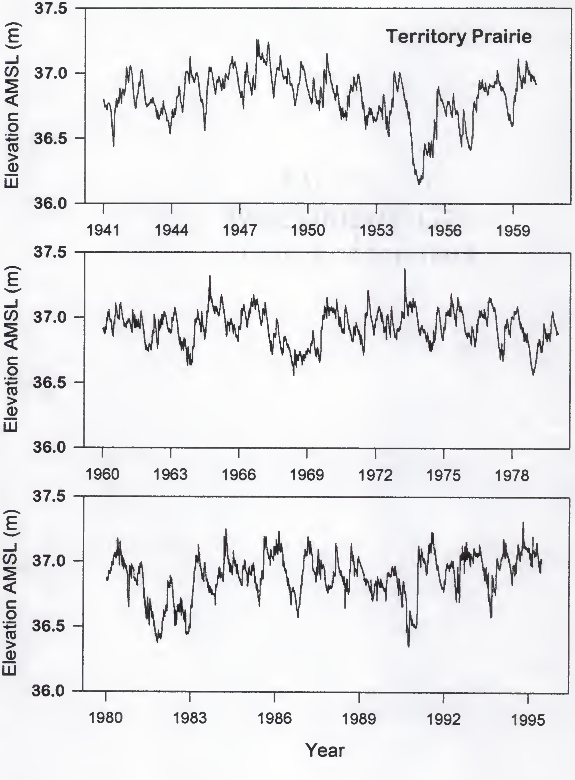


Figure 2-2--continued.

Table 2-2. Summary parameters of water level recorders installed at Okefenokee National Wildlife Refuge during 12-5-1979 through 6-15-1995. Elevations are in meters above mean sea level. Basin delineation is discussed in the Swamp Basin Delineation and Characterization section.

Basin and Station[a]	Mean Daily Water Surface Elevation	Variance in Daily Water Surface Elevation	Minimum Daily Water Surface Elevation	Maximum Daily Water Surface Elevation
Northwest Basin				
Suwannee Creek (digital)	36.96	0.12	36.13	38.07
Suwannee Creek (chart)	36.39	0.04	35.77	36.76
Floyd's Prairie	35.64	0.02	35.26	36.03
Sapling Prairie	37.08	0.02	36.74	37.36
Suwannee River	34.65	0.27	33.31	35.39
Billy's Lake	35.03	0.05	34.53	35.52
SCFSP	34.95	0.08	34.07	36.04
Sill (Brown Trail)	35.08	0.23	33.29	36.10
Craven's Hammock	35.51	0.08	35.05	36.11
Northeast Basin				
Kingfisher Landing	37.55	0.02	37.25	37.86
Double Lakes	37.54	0.02	37.16	37.86
Durdin Prairie	37.35	0.004	37.17	37.49
Central Basin				
SCRA	36.52	0.05	35.72	37.04
Seagrove Lake	36.63	0.04	36.00	37.10

Basin and Station[a]	Mean Daily Water Surface Elevation	Variance in Daily Water Surface Elevation	Minimum Daily Water Surface Elevation	Maximum Daily Water Surface Elevation
Chase Prairie	36.49	0.01	36.75	36.02
Gannett Lake	36.78	0.03	36.17	37.17
Territory Prairie	36.90	0.03	36.37	37.31
Chesser Prairie	36.63	0.02	36.26	36.91
Coffee Bay	36.81	0.04	36.13	37.08
Sweetwater Creek	34.56	0.02	34.11	35.07
Honey Prairie	37.15	0.01	36.86	37.31
Southeast Basin				
Moonshine Ridge	35.81	0.01	35.55	36.01
Soldier's Camp	34.18	0.05	33.70	34.59
Southwest Basin				
Sapp Prairie (chart)	36.61	0.01	36.36	36.91
Sapp Prairie (digital)	36.47	0.02	36.13	36.72
Cypress Creek	34.14	0.06	33.35	34.69

[a] Operating interval duration for each station is included in Table 2-1.

Table 2-3. Summary of water level and precipitation recorder performance during 12-5-1979 through 6-15-1995 at Okefenokee National Wildlife Refuge.

Station	Type of Data Collected	Duration of Recorder Installment (days)	Duration of Recorder Operation (days)	Proportion of Days Recorder Functioning Properly
Chase Prairie	water level	5519	4358	79
Double Lakes	water level	5672	4343	77
Gannett Lake	water level	5490	3843	70
Kingfisher Landing	water level	5635	3553	63
Moonshine Ridge	water level	4851	2277	47
Sapp Prairie (chart)	water level	2882	1482	51
SCFSP	water level	5672	4071	72
SCRA	water level	5672	5017	88
Seagrove Lake	water level	5672	4328	76
Sill (Brown Trail)	water level	5614	2649	47
Soldier's Camp	water level	694	681	98
Suwannee Creek (chart)	water level	878	854	97
Territory Prairie	water level	5519	3748	68
Billy's Lake	water level	1156	1141	99
Chesser Prairie	water level	862	791	92
Coffee Bay	water level	1172	967	83

Station	Type of Data Collected	Duration of Recorder Installment (days)	Duration of Recorder Operation (days)	Proportion of Days Recorder Functioning Properly
Craven's Hammock	water level	1171	1039	89
Cypress Creek	water level	1169	1036	89
Durdin Prairie	water level	1102	963	87
Floyd's Prairie	water level	1170	1117	95
Honey Prairie	water level	1101	224	20
Suwannee River	water level	1170	1060	91
Sapp Prairie (digital)	water level	862	677	79
Sapling Prairie	water level	862	639	74
Suwannee Creek (digital)	water level	1155	975	84
Sweetwater Creek	water level	1170	883	75
Craven's Hammock	precipitation	1162	997	86
Coffee Bay	precipitation	1171	960	82
Durdin Prairie	precipitation	1176	1051	89
Floyd's Prairie	precipitation	1156	1103	95
Honey Prairie	precipitation	924	236	26
Sapling Prairie	precipitation	749	635	85

Table 2-3--continued

Station	Type of Data Collected	Duration of Recorder Installment (days)	Duration of Recorder Operation (days)	Proportion of Days Recorder Functioning Properly
Sapp Prairie (digital)	precipitation	684	663	97
Suwannee River	precipitation	1126	1033	92
SCFSP	precipitation	5501	2407	56
Double Lakes	precipitation	5375	3469	65
SCRA	precipitation	5784	4034	70
Chase Prairie	precipitation	5454	3650	67
Seagrove Lake	precipitation	5553	3342	60
Kingfisher Landing	precipitation	5634	3017	54
Gannett Lake	precipitation	5344	3853	72
Territory Prairie	precipitation	5425	3523	65
Sill (Brown Trail)	precipitation	5605	2798	50
Moonshine Ridge	precipitation	4458	2398	54
Suwannee Creek (chart)	precipitation	878	766	87
Soldier's Camp	precipitation	704	552	78
Sapp Prairie (chart)	precipitation	2888	1161	40

chart recorder operation, 46% operated for >75% of the installation period. Over the installation period of digital recorders (862-1172 days), 85% functioned for >75% of the interval. If the operation period is pro-rated to the same length for both recorder types (first 1054 days after installation), 86% of the chart recorders were operating for >75% of the interval; 81% of the digital recorders had similar performance (Table 2-4). These performance ratings should be considered in management of the monitoring network. The initial performance of the chart recorders surpasses that of the digital equipment; their longevity is proven; the record is continuous (not point observations by time intervals); and, if data retrieval and station maintenance are regular, data management procedures can be as automated as that for digital recorders. New Steven's chart recorders and platforms should be considered for replacement of old instrumentation, especially for remote, seldom-visited sites. Most of the existing units are experiencing failure due to decaying installation platforms, not necessarily due to failure of the recording equipment. Repairs on the chart instruments can generally be made in place without the diagnostic equipment needed for digital units. The digital units should be located in the more accessible locations, since maintenance frequency is generally higher, recorders are less reliable, and diagnoses are more difficult.

Estimation of Missing Water Level Data

The swamp hydrology model requires starting water depths throughout the swamp and a dataset of bi-weekly, average water depths for model calibration.

Table 2-4. Summary of water level recorder performance prorated to the initial operating period (1054 days).

Station	Duration of Recorder Operation (days)	Proportion of Days Recorder Functioning Properly
Billy's Lake	1143	99
Chesser Prairie	793	92
Coffee Bay	960	82
Cypress Creek	1027	89
Durdin Prairie	964	82
Floyd's Prairie	1117	97
Honey Prairie	224	24
Sapling Prairie	639	85
Sapp Prairie (digital)	667	98
Suwannee Creek (digital)	1009	85
Suwannee River	1058	91
Sweetwater Creek	878	76
Craven's Hammock	1039	89
SCFSP	715	68
Double Lakes	958	91
SCRA	1017	97
Chase Prairie	1017	97
Seagrove Lake	974	92
Kingfisher Landing	994	94
Gannett Lake	872	83
Territory Prairie	746	71
Sill (Brown Trail)	886	84

Station	Duration of Recorder Operation (days)	Proportion of Days Recorder Functioning Properly
Moonshine Ridge	874	83
Suwannee Creek (chart)	854	97
Soldier's Camp	681	97
Sapp Prairie (chart)	629	60

Swamp water level recorders and staff gauges provided a partial daily water level record, due to malfunctioning recorders; estimates of missing daily data were needed to calculate average bi-weekly water depths for the model, and to estimate vegetation species-hydroperiod relationships (see Chapter 6). Correlation and simple linear regression procedures were used to estimate missing daily data for each recorder. During 1980-1995 there were only 6 bi-weekly intervals when all recorders were operating concurrently. Therefore comparisons for the best correlations and regressions were calculated for reduced intervals only among local recorder pairs (the nearest 1-3 stations, using relationships in sequence of highest to lowest r_{adj}^2 until a complete daily dataset resulted) for the 1980-1995 missing data. All regression pairs met assumptions of linearity, independence and normality of residuals, independence of data, and non-autocorrelated residuals (Durbin-Watson D) (Myers 1990). Most data pairs were not successive; there were frequent errors in the recorded data so that sequential days with recorded data did not occur at every recorder simultaneously. Only non-regressed, original recorder data were used in the

correlation and regression calculations. Several regression relationships were necessary for each station to ensure complete data coverage during the interval. Missing data for all chart and digital recorder stations were estimated for 1941-1979 using regression relationships between the stations and the long-term daily staff gauge at SCFSP or SCRA (using whichever had the higher correlation) (Myers 1990). Missing chart station data during 1980-1991 were estimated with regressions among chart station data. Since no digital recorders were operating before 1992, digital station data for 1980-1991 were estimated with equations developed in regressions of chart and digital station data for 1992-1995. Best regression relationships between chart and/or digital stations were used to estimate missing data at all stations during 1992-1995. Best correlation pairs, regression coefficients ($P < 0.05$) and equations, and missing data estimation intervals are listed in Table 2-5.

Starting water depth and biweekly average water depth were needed to start and calibrate the hydrology model. The daily data (actual and regression-estimated) at 30 stations were averaged for biweekly intervals during 1941-1993, and interpolated using ARCGRID's (version 7.0, ESRI, Inc., Redlands, CA, 92373) circular kriging algorithm to create biweekly water depth estimates in each of the model's 10,672 (500X500 m) grid cells. Several of the recorders were at locations with topographic, and therefore water depth variability, at a resolution smaller than that of the model (500X500 m). Therefore model output was compared to both the interpolated data and the original recorder data to determine model performance. In

Table 2-5. Best correlation pairs and regression equations used to estimate missing water level recorder data during 1941-1995.

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
1941-1979			
Billy's Lake	SCFSP	0.9952	y = 1.01883x - 0.655750
Chase Prairie	SCRA	0.8352	y = 0.474747x + 19.13962
Chesser Prairie	SCRA	0.9188	y = 0.919405x + 2.995167
Coffee Bay	SCRA	0.9197	y = 1.177936x - 6.347071
Cravens Hammock	SCFSP	0.9685	y = 1.117538x - 3.67679
Cypress Creek	SCRA	0.8646	y = 1.555137x - 22.893495
Double Lakes	SCRA	0.5675	y = 0.481662x + 19.95717
Durdin Prairie	SCFSP	0.8856	y = 0.21442x + 29.80959
Floyd's Prairie	SCFSP	0.9859	y = 0.636968x + 13.31684
Gannett Lake	SCRA	0.8518	y = 0.70466x + 11.05423
Honey Prairie	SCFSP	0.7635	y = 0.469929x + 20.665821
Kingfisher Landing	SCRA	0.7111	y = 0.49819x + 19.33553
Moonshine Ridge	SCRA	0.7427	y = 0.343284x + 23.25431
Suwannee River	SCFSP	0.7884	y = 2.331444x - 47.0322
Sapp Prairie (chart)	SCFSP	0.7302	y = 0.306802x + 25.85369
Sapp Prairie (digital)	SCRA	0.9536	y = 0.807310x + 6.93015
Sapling Prairie	SCFSP	0.9869	y = 0.67846x + 13.30181
Suwannee Creek (chart)	SCFSP	0.4145	y = 0.509266x + 18.80288

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
Suwannee Creek (digital)	SCFSP	0.6438	y = 1.037264x + 0.562694
Seagrove Lake	SCRA	0.9190	y = 0.878125x + 4.538393
Sill (Brown Trail)	SCFSP	0.3881	y = 1.1719092x - 6.25709
Soldier's Camp	SCRA	0.6514	y = 0.715641x + 8.136278
Sweetwater Creek	SCRA	0.8757	y = 0.767672x + 6.413319
Territory Prairie	SCRA	0.7243	y = 0.66398x + 12.64588
1980-1991			
SCFSP	Gannett Lake	0.7670	y = 1.288821x - 12.483251
	SCRA	0.7160	y = 1.075264x - 4.308377
	Chase Prairie	0.6600	y = 1.973633x - 37.028758
SCRA	Seagrove Lake	0.8955	y = 1.006442x - 0.323629
	Gannett Lake	0.8811	y = 1.452196x - 16.932219
	Chase Prairie	0.8428	y = 1.73762x - 26.855268
Chase Prairie	Territory Prairie	0.8517	y = 0.612281x + 13.896672
	SCRA	0.8428	y = 1.73762x - 26.855268
	Seagrove Lake	0.7067	y = 0.477543x + 18.991341
Territory Prairie	Chase Prairie	0.8517	y = 0.612281x + 13.896672
	Seagrove Lake	0.6235	y = 0.692281x + 11.529932
Double Lakes	Kingfisher	0.8672	y = 0.957434x + 1.587892
	Landing	0.6255	y = 0.381085x + 24.392432
	Suwannee Creek (chart)	0.6153	y = 0.654627x + 13.40319
	Territory Prairie		
Seagrove Lake	SCRA	0.8955	y = 0.890131x + 4.100752
	Chase Prairie	0.7067	y = 1.482181x - 17.445768
	Territory Prairie	0.6235	y = 0.902959x + 3.326217

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
Sill (Brown Trail)	Soldier's Camp	0.4156	y = 0.888818x + 4.774716
	Suwannee Creek (chart)	0.3987	y = 0.733971x + 8.450264
	Sapp Prairie (chart)	0.3642	y = 1.692363x - 26.697464
	SCFSP	0.3596	y = 1.392526x - 13.735103
Kingfisher Landing	Double Lakes	0.8670	y = 0.905729x + 3.545421
	SCRA	0.7111	y = 0.49819x + 19.33553
	Chase Prairie	0.6601	y = 0.953498x + 2.767062
Gannett Lake	SCRA	0.8811	y = 0.614203x + 14.379507
	SCFSP	0.7670	y = 0.595840x + 15.974003
	Seagrove Lake	0.7706	y = 0.770187x + 8.587597
Sapp Prairie (chart)	Soldier's Camp	0.7622	y = 0.377933x + 23.607006
	Gannett Lake	0.5655	y = 0.526923x + 17.55543
	SCFSP	0.5616	y = 0.26444x + 27.336647
Soldier's Camp	Sapp Prairie (chart)	0.7622	y = 0.377933x + 23.607006
	Gannett Lake	0.6343	y = 0.61218x + 0.68960
	Suwannee Creek (chart)	0.6432	y = 0.802501x + 5.000845
	SCRA	0.5300	y = 0.636551x + 11.030303
Moonshine Ridge	Gannett Lake	0.5700	y = 0.46871x + 19.728948
	SCRA	0.4873	y = 0.353624x + 22.878873
	Seagrove Lake	0.3803	y = 0.30953x + 24.463134
Suwannee Creek (chart)	Soldier's Camp	0.6432	y = 0.811783x + 8.608739
	Double Lakes	0.6309	y = 1.702882x - 27.323189
	Kingfisher Landing	0.5284	y = 1.317963x - 12.913351
Coffee Bay	Seagrove Lake	0.9200	y = 1.16484x - 5.94484
	SCRA	0.9197	y = 1.177936x - 6.347071
	Chase Prairie	0.7600	y = 2.263836x - 45.920005

Table 2-5--continued.

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
Chesser Prairie	Seagrove Lake	0.9863	y = 1.044685x - 1.672174
	SCRA	0.9841	y = 0.998382x + 0.09812
	SCFSP	0.9648	y = 0.819478x + 7.957763
Durdin Prairie	SCFSP	0.8881	y = 0.207952x + 30.030537
	Territory Prairie	0.7600	y = 0.43822x + 21.128403
	Double Lakes	0.5960	y = 0.530182x + 16.902973
Sapling Prairie	SCFSP	0.9233	y = 0.679905x + 13.257842
	SCRA	0.9083	y = 0.877289x + 4.960941
	Double Lakes	0.6800	y = 1.77944x - 31.546924
Billy's Lake	SCFSP	0.9952	y = 1.018813x - 0.655750
	SCRA	0.8815	y = 1.178149x - 8.135219
Suwannee River	SCFSP	0.7884	y = 2.331444x - 47.0322
Craven's Hammock	SCFSP	0.8662	y = 1.095096x - 2.897342
	SCRA	0.7525	y = 1.254816x - 10.514335
Floyd's Prairie	SCFSP	0.9280	y = 0.629658x + 13.569917
	Seagrove Lake	0.6400	y = 0.845072x + 4.604841
	Territory Prairie	0.6300	y = 0.935060x + 1.052165
Suwannee Creek (digital)	SCFSP	0.6438	y = 1.037264x + 0.562694
	Double Lakes	0.4471	y = 2.74672x - 68.9186
Honey Prairie	SCFSP	0.7205	y = 0.42043x + 22.383008
	Seagrove Lake	0.6200	y = 0.520723x + 17.994814
Sweetwater Creek	Seagrove Lake	0.6100	y = 0.870450x + 2.578536
	Gannett Lake	0.5100	y = 0.657803x + 10.309298
	SCRA	0.4878	y = 0.61605x + 11.963422
	SCFSP	0.4703	y = 0.50043x + 17.004948
Cypress Creek	SCRA	0.8646	y = 1.555137x - 22.893495
	SCFSP	0.8501	y = 1.292408x - 11.177002
	Seagrove Lake	0.8300	y = 1.672840x - 27.301101
Sapp Prairie (digital)	SCRA	0.9536	y = 0.807310x + 6.93015
	Seagrove Lake	0.9200	y = 0.78096x + 7.837301
	Chase Prairie	0.8300	y = 1.627919x - 23.007385

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
1992-1995			
Sill (Brown Trail)	Suwannee River	0.9523	y = 1.196004x - 6.831348
	Billy's Lake	0.7369	y = 2.369154x - 48.318059
SCFSP	Billy's Lake	0.9955	y = 0.979881x + 0.701561
	Floyd's Prairie	0.9245	y = 1.479422x - 17.678245
	Suwannee River	0.8158	y = 0.382741x + 21.745865
SCRA	Chesser Prairie	0.9895	y = 0.976399x + 0.824623
	Coffee Bay	0.9197	y = 0.782395x + 7.836545
Chase Prairie	Sapp Prairie (digital)	0.8266	y = 0.510426x + 17.923383
	Coffee Bay	0.7582	y = 0.336781x + 24.149895
Territory Prairie	Durdin Prairie	0.7592	y = 1.74278x - 28.079932
	Floyd's Prairie	0.6279	y = 0.678246x + 12.817394
	Billy's Lake	0.6024	y = 0.449532x + 21.23899
Double Lakes	Sapling Prairie	0.6819	y = 0.387576x + 24.193191
	Durdin Prairie	0.5957	y = 1.137446x - 3.929222
	Floyd's Prairie	0.5289	y = 0.419301x + 23.597785
Seagrove Lake	Chesser Prairie	0.9863	y = 0.944417x + 2.070188
	Sapp Prairie (digital)	0.9207	y = 1.178908x - 6.328907
	Coffee Bay	0.9115	y = 0.0784023x + 7.845797
Kingfisher Landing	Double Lakes	0.8670	y = 0.905729x + 3.545421
	SCRA	0.7111	y = 0.49819x + 19.33553
	Chase Prairie	0.6601	y = 0.953498x + 2.767062
Gannett Lake	Coffee Bay	0.6794	y = 0.60133x + 14.705007
	Chesser Prairie	0.6401	y = 0.763805x + 8.822456
	Sapp Prairie (digital)	0.6218	y = 0.958325x + 1.849815
Sapp Prairie (chart)	Gannett Lake	0.5655	y = 0.516923x + 17.55543
	SCFSP	0.5616	y = 0.26444x + 27.336647
	Seagrove Lake	0.4273	y = 0.360912x + 23.374758

Table 2-5--continued.

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
Soldier's Camp	Gannett Lake SCRA	0.6343 0.5300	y = 0.91218x + 0.68960 y = 0.636551x + 11.030303
Moonshine Landing	Chesser Prairie Sapp Prairie (digital) Coffee Bay	0.7489 0.6942 0.4970	y = 0.477916x + 18.287191 y = 0.561003x + 15.322119 y = 0.364872x + 22.377580
Suwannee Creek (chart)	Double Lakes	0.6256	y = 1.659745x - 27.11490
Coffee Bay	Chesser Prairie SCRA Sapp Prairie (digital)	0.9308 0.9197 0.9080	y = 1.276304x - 9.981905 y = 1.177936x - 6.347071 y = 1.5193x - 18.647531
Chesser Prairie	Seagrove Lake SCRA SCFSP	0.9863 0.9841 0.9648	y = 1.044685x - 1.672174 y = 0.998382x + 0.09812 y = 0.819478x + 7.957763
Durdin Prairie	SCFSP Sapling Prairie Territory Prairie	0.8881 0.7719 0.7600	y = 0.207952x + 30.030537 y = 0.344244x + 24.585459 y = 0.43822x + 21.128403
Sapling Prairie	SCFSP SCRA Craven's Hammock	0.9233 0.9083 0.8192	y = 0.679915x + 13.257842 y = 0.877289x + 4.960941 y = 0.437932x + 21.542202
Billy's Lake	SCFSP Floyd's Prairie SCRA	0.9952 0.9215 0.8815	y = 1.018813x - 0.655750 y = 1.401629x - 14.917255 y = 1.178149x - 8.135219
Suwannee River	SCFSP	0.7884	y = 2.331444x - 47.0322
Craven's Hammock	SCFSP Billy's Lake Sapling Prairie	0.8662 0.8372 0.8192	y = 1.095086x - 2.897342 y = 1.226685x - 7.493928 y = 1.880079x - 34.234817
Floyd's Prairie	SCFSP Billy's Lake Seagrove Lake	0.9280 0.9226 0.6400	y = 0.629658x + 13.569917 y = 0.658218x + 12.578014 y = 0.845072x + 4.604841

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj}[a]	Regression Equation to Estimate Y
Suwannee Creek (digital)	Craven's Hammock Sapling Prairie SCFSP	0.8432 0.6972 0.6438	y = 1.095831x - 1.956902 y = 2.142633x - 42.481572 y = 1.037264x + 0.562694
Honey Prairie	Sapp Prairie (digital) Chesser Prairie SCFSP SCRA	0.9326 0.9248 0.7205 0.6566	y = 0.926357x + 3.313969 y = 0.688285x + 11.898168 y = 0.420434x + 22.383008 y = 0.499013x + 18.817358
Sweetwater Creek	Seagrove Lake Chesser Prairie Sapp Prairie (digital)	0.6100 0.5997 0.5685	y = 0.87045x + 2.578536 y = 0.819802x + 4.504097 y = 0.925475x + 0.768341
Cypress Creek	Sapp Prairie (digital) Chesser Prairie SCRA Seagrove Lake	0.9467 0.8669 0.8646 0.8300	y = 2.222674x - 46.997072 y = 1.815132x - 32.417015 y = 1.555137x - 22.893495 y = 1.67284x - 27.301101
Sapp Prairie (digital)	SCRA Cypress Creek Chesser Prairie	0.9536 0.9467 0.9226	y = 0.80731x + 6.93015 y = 0.426513x + 21.941910 y = 0.789828x + 7.541488

[a] All regression relationships were significant at $P \leq 0.05$ or less.

most cases model performance that corresponded better with the original recorder data represented stations with detail at a resolution smaller than the 500X500 m cell size of the model (e.g., the recorder was located in a ditch, small lake, or stream bed). Recorder data estimated with regression equations and interpolated for model performance evaluations are plotted in Figure 2-2.

Correlative relationships that permit missing data estimation also indicate redundancies in the water level recorder network. Although these redundancies were useful in model database development and estimating missing data using regression relationships, they represent a significant investment of personnel required to maintain the recorders and database. There are several approaches to eliminating redundant stations in the recorder network. Selecting stations depends on the intended use of the recorder data. If the interest is in representing local uniqueness while eliminating redundant stations, 17 stations should be maintained. These include unique stations (Figure 2-1; Craven's Hammock, Sweetwater Creek, Durdin Prairie, Double Lakes, Kingfisher Landing, Moonshine Landing, Sapling Prairie, Floyd's Prairie, Suwannee River, Suwannee Creek, Gannett Lake, Cypress Creek, Soldiers Camp, Territory Prairie, Chase Prairie) and redundant stations which could be used to estimate missing water elevations at other stations (SCFSP or Billy's Lake, and Seagrove Lake or Chesser Prairie). If the interest is in maintaining the recorder network for the best predictions of missing data, there are 17 stations that should be maintained. Stations highly correlated ($r_{adj}^2 > 0.90$) with at least one other station should be maintained, as well as those most unique (not highly correlated with at least one other station). Stations having highly correlative relationships with other stations include SCRA, Seagrove Lake, Sapp Prairie (digital), Suwannee River, Floyd's Prairie, and SCFSP. Those that are most unique ($r_{adj}^2 < 0.90$) include Chase Prairie, Craven's Hammock, Durdin Prairie, Double Lakes, Gannett Lake, Kingfisher Landing, Moonshine Ridge, Soldier's Camp,

Suwannee Creek (digital), Sweetwater Creek, and Territory Prairie. If the interest is in eliminating redundancy to minimize resources needed to represent temporal and spatial variability in water surface elevations, 13 stations should be maintained. These are SCRA ($r_{adj}^2 > 0.90$ with Chesser Prairie, Coffee Bay, Sapling Prairie, Seagrove Lake), SCFSP ($r_{adj}^2 > 0.90$ with Billy's Lake, Floyd's Prairie, Chesser Prairie, Craven's Hammock, Sapling Prairie), Sapp Prairie digital ($r_{adj}^2 > 0.90$ with Cypress Creek, Chase Prairie), Suwannee River ($r_{adj}^2 > 0.90$ with Brown Trail-Sill), and the unique stations at Durdin Prairie, Double Lakes, Territory Prairie, Gannett Lake, Kingfisher Landing, Moonshine Ridge, Soldiers Camp, Suwannee Creek (digital), and Sweetwater Creek. Time and resources saved by eliminating network redundancies should be invested in improving recorder performance at the remaining stations. Without these redundant stations, missing data estimations with the recorder relationships in Table 2-5 will not be possible. However, biweekly water level fluctuation estimates can be made with the swamp hydrology model (see Chapter 3), and model performance accuracy can be assessed with data recorded at the remaining stations.

Precipitation Gauge Network Assessment

Background

Considerable refuge resources are devoted to maintenance of precipitation recorders and management of retrieved data. These data are used to estimate area daily rainfall. It was uncertain how representative these recorder data were of actual

daily area rainfall, because the variability of daily rainfall had not been examined. It was possible that variability in daily area rainfall exceeded network resolution for daily area rainfall calculations, and that these data would be more appropriately summarized over longer periods (weeks to months) to estimate average daily rainfall throughout the swamp.

Accuracy of the precipitation recorder network in estimating area rainfall was assessed using a technique that compares variation in precipitation measured at recording stations, weighted by the area of coverage for the measurement, and adjusted by the spatial and relative variances and covariances calculated among stations and within the watershed (Still and Shih 1990, Shih 1982). Total precipitation variation in a watershed is due to variation at individual stations and variation among stations, or spatial variability, as

$$s^2(\bar{x}) = s_r^2(\bar{x}) + s_c^2(\bar{x})$$

where

$s^2(\bar{x})$ = total variance of mean rainfall.
$s_r^2(\bar{x})$ = relative variance of mean rainfall, and
$s_c^2(\bar{x})$ = spatial variation of mean rainfall.

Relative variance is dependent on the network density; it can be reduced by increasing the density of recording stations (Shih 1982). Relative variance can be calculated to represent randomly placed stations (Method A), or stations allocated randomly among strata (Method B), or located relative to within-stratum variability (Method C):

$$\text{Method A} \quad s_r^2(\bar{x}) = (1/N)\,(\hat{s}_o^2 - \hat{s}_{okl})$$

$$\text{Method B} \quad s_r^2(\bar{x}) = \sum_{i=1}^{n} (W_i^2/N_i)\,(\hat{s}_{oi}^2 - \hat{s}_{okli})$$

$$\text{Method C} \quad s_r^2(\bar{x}) = (1/N)\,[\,\sum_{i=1}^{n} (W_i)\,\{(\hat{s}_{oi} - \hat{s}_{okli})^2\}^{1/2}]$$

where

N = the total number of stations
N_i = the number of stations in the *i*th stratum
$\hat{s}_o^2$ = the average variance within the watershed
$\hat{s}_{okl}$ = the average covariance within the watershed
i, j = the stratum
n = the number of strata
W_i = the area ratio for the *i*th stratum
$\hat{s}_{oi}^2$ = the average variance within the *i*th stratum
$\hat{s}_{okli}$ = the average covariance within the *i*th stratum.

Spatial variance reflects a characteristic of the watershed and does not necessarily decrease with increasing network density (Shih 1982). It is affected by within-stratum covariance and the proportional area of the stratum relative to the watershed. Station placement should maximize stratum homogeneity; spatial variance should decrease if each stratum represents homogeneous areas of rainfall. Increased precision in rainfall estimates should then result with non-random placement of gauges in the watershed (Methods B and C) (Still and Shih 1990, Shih 1982). Spatial variance is calculated by

$$\text{Method A} \quad s_c^2(\bar{x}) = \hat{s}_{okl}$$

$$\text{Methods B and C} \quad s_c^2(\bar{x}) = \sum_{i=1}^{n} (W_i^2)(\hat{s}_{okli}) + 2\sum_{i=1}^{n} \sum_{\substack{j=1 \\ i>j}}^{n} \{(W_i\,W_j)(\hat{s}_{oklij})\}$$

where:

$\hat{s}_{ok1ij}$ = the average covariance between the *i*th and *j*th strata.

These parameters describe the variability of watershed precipitation. Based on the total variance of the mean rainfall, the number of stations required to estimate mean rainfall within a desired statistical accuracy can be calculated (Still and Shih 1990, Shih 1982). For random gauge placement (Method A) and specified α, β, and mean ($\bar{x}$) rainfall within the watershed,

$$N = t_\alpha^2 \{(\hat{s}_o^2 - \hat{s}_{okl}) / (\beta \bar{x})^2\}.$$

For stratified gauge placement (Methods B and C),

$$N = [\{t_\alpha \sum_{i=1}^{n} W_i (\hat{s}_{oi}^2 - \hat{s}_{okli})^{1/2}\} / \{\beta \sum_{i=1}^{n} W_i \bar{x}_i\}]^2,$$

where $\bar{x}_i$ is the mean rainfall within the *i*th stratum. Accuracy of the gauging network is proportional to the variability of rainfall at each station, the size of the basin represented by the gauge, and the amount of variability among stations (Shih 1982). The proportion of gauges to be allocated to each stratum can be calculated based on a weighted ratio,

$$N_i = NC_i,$$

where

$$C_i = \{W_i (\hat{s}_{oi}2 - \hat{s}_{okli})^{1/2}\} / \{\sum_{i=1}^{n} Wi (\hat{s}_{oi}^2 - \hat{s}_{okli})\}.$$

Stations can be relocated to better represent the spatial variance of rainfall in the watershed, based on this ratio.

Methods

Two subsets of precipitation recorder stations were selected for assessment of network accuracy. One subset (subset 1) contained all stations in the network with daily precipitation data for at least half of the recording days during 31 March 1992-3 July 1995. This subset represented a recorder network with 14 stations (Chase, Territory, Floyds, Durdin, Sapp, and Sapling Prairies, Kingfisher Landing, Double Lakes, Seagrove Lake, SCRA, SCFSP, Cravens Hammock, Coffee Bay, and Suwannee River). The second subset (subset 2) eliminated 3 stations from subset 1, to contain only those stations that were easily accessed; this subset represented a network with 11 stations (Chase, Territory, Durdin, and Sapp Prairies, Kingfisher Landing, Double Lakes, Seagrove Lake, SCRA, SCFSP, Coffee Bay, and Suwannee River). Daily precipitation data were averaged for each station by daily, bi-weekly, and monthly intervals (Table 2-6), i.e., daily average precipitation was calculated by summarizing over days, bi-weekly, and monthly periods. Interpolated surfaces of daily averages calculated from daily, bi-weekly, and monthly average data were created using the ARCVIEW inverse-distance-weighted (IDW) procedure, and contoured at 1 mm. Several contouring intervals were calculated for each subset and average to determine minimum differences among interpolated stations; intervals less than 1 mm resulted in partitioning the stations into single station strata (i.e., each station was isolated), whereas intervals greater than 3 mm resulted in no contours, i.e., all stations belonged to 1 stratum. This means that measured differences among stations in average daily rainfall volume calculated by daily,

Table 2-6. Daily average precipitation estimated with measurements made daily, and approximated with biweekly or monthly calculations of daily averages during 31 March 1992 - 3 July 1995.

Station	Total Precipitation during Interval (cm)	Daily estimate of Precipitation Average (cm)	Biweekly Estimate of Daily Precipitation Average (cm)	Monthly Estimate of Daily Precipitation Average (cm)	Duration of Recorder Installment (days)	Proportion of Days Recorder Functioning Properly (%)	Recorder in 14-station Network	Recorder in 11-station Network
Coffee Bay	273.4	0.29	0.29	0.29	960	81	x	x
Durdin Prairie	348.6	0.33	0.32	0.31	1051	88	x	x
Floyd's Prairie	402.6	0.37	0.38	0.40	1103	93	x	
Sapling Prairie	184.1	0.29	0.28	0.28	635	53	x	
Sapp Prairie (digital)	187.0	0.28	0.28	0.29	663	56	x	x
Suwannee River	309.3	0.30	0.29	0.29	1033	87	x	x
Craven's Hammock	358.4	0.36	0.37	0.40	997	84	x	
SCRA	238.3	0.27	0.29	0.34	897	75	x	x
Double Lakes	244.4	0.28	0.27	0.30	868	73	x	x
Kingfisher Landing	259.6	0.31	0.30	0.32	830	70	x	x
Chase Prairie	197.8	0.28	0.26	0.24	717	60	x	x
Territory Prairie	243.9	0.34	0.33	0.32	712	60	x	x
Seagrove Lake	126.2	0.20	0.20	0.19	644	54	x	x
SCFSP	273.2	0.30	0.29	0.30	901	76	x	x

biweekly, or monthly periods are generally less than 1-3 mm. These interpolated surfaces provided groupings of stations within strata; for each interval, stations with daily averages that were within 1 mm of each other were grouped in the same stratum. Groupings of stations among strata, and strata area, variances, covariances, required number of stations for specified network accuracy, and allocation of gauges among strata are listed in Tables 2-7 and 2-8. Strata delineations for daily, biweekly, and monthly networks of 11 and 14 stations are given in Figures 2-3 through 2-8.

Results of Precipitation Network Analysis

Relative variance of the recording network is dependent on the number of stations, and how recorders are partitioned among strata. In the 14 gauge network the relative variances of daily averages from daily data calculated by Methods A, B, and C were 0.0364, 0.0463, and 0.0437, respectively. The similarity in these variances suggest that either method (random or stratified) would be appropriate for relative variance calculation, since within-stratum variability is low. Therefore, stratified allocation of gauges affords no increase in precision of relative variance over randomly sampling the watershed. This was also true of daily averages calculated with bi-weekly and monthly data (Table 2-8). However, there are differences in spatial variance of daily data calculated by methods A, B, and C. The random sample method (A) results in slightly higher spatial variance for daily rainfall estimates from daily data (0.4937) than the stratified sample (0.3812). This suggests that rainfall distribution is not homogeneous throughout the watershed, and that the network benefits from stratification. This difference does not occur when the daily data are summarized over bi-weekly and

Table 2-7. Stratum and station variances and covariances of daily precipitation estimates, averaged by day, biweekly, and monthly during 31 March 1992-3 July 1995. Symbology is defined in the chapter text.

Network, Estimate, Strata	Station	$\hat{S}_o^2$	$\hat{S}_{okl}$	$\hat{S}^2$	$\hat{S}_{oi}^2$	$\hat{S}_{okli}$	Between Strata Average Covariance			Stratum Area (ha)	W_i
N=14, Daily							1	2	3		
1	Sapling Prairie	1.00	0.50	0.73	0.81	0.28	---	0.47	0.31	12141	0.08
	Double Lakes			0.90							
2	Kingfisher Landing			1.32	1.17	0.51	0.47	---	0.37	74620	0.47
	Durdin Prairie			1.10							
	Territory Prairie			1.39							
	Floyd's Prairie			1.16							
	SCFSP			1.35							
	Suwannee River			0.78							
	Cravens Hammock			1.11							
3	Chase Prairie			1.08	0.84	0.27	0.31	0.37	---	73687	0.46
	Seagrove Lake			0.59							
	SCRA			1.13							
	Sapp Prairie (digital)			0.64							
	Coffee Bay			0.77							
N=14, Biweekly							1	2	3		

Table 2-7--continued.

Network, Estimate, Strata	Station	$\hat{S}_o^2$	$\hat{S}_{okl}$	$\hat{S}^2$	$\hat{S}_{oi}^2$	$\hat{S}_{okli}$	Between Strata Average Covariance	Stratum Area (ha)	W_i
1	Sapling Prairie	0.11	0.06	0.06	0.07	0.02	--- 0.06	17488	0.11
	Double Lakes			0.08			0.04		
2	Kingfisher Landing			0.16	0.15	0.09	0.06 ---	54857	0.34
	Durdin Prairie			0.09			0.07		
	Territory Prairie			0.16					
	Floyd's Prairie			0.16					
	Craven's Hammock			0.15					
3	Chase Prairie			0.09	0.10	0.06	0.04 0.07	88113	0.55
	SCFSP			0.11			---		
	Suwannee River			0.08					
	Coffee Bay			0.09					
	SCRA			0.20					
	Seagrove Lake			0.08					
	Sapp Prairie (digital)			0.07					
N=14, Monthly							1 2 3 4 5		
1	Sapling Prairie	0.08	0.04	0.04	0.04	0	--- 0.03 0.03 0.02 0.02	10425	0.06

Table 2-7--continued.

Network, Estimate, Strata	Station	$\hat{s}_o^2$	$\hat{s}_{okl}$	$\hat{s}^2$	$\hat{s}_{oi}^2$	$\hat{s}_{okli}$	Between Strata Average Covariance				Stratum Area (ha)	W_i
2	Double Lakes			0.06	0.10	0.04	0.03 0.05	---	0.04	0.03	72191	0.45
	Kingfisher Landing			0.10								
	Durdin Prairie			0.05								
	Territory Prairie			0.08								
	Floyd's Prairie			0.14								
	Craven's Hammock			0.17								
3	Suwannee River			0.06	0.06	0.04	0.03 0.05	0.03	---	0.04	3436	0.02
	SCFSP			0.06								
4	Chase Prairie			0.05	0.05	0.03	0.03 0.04	0.03	0.04	---	72880	0.45
	Coffee Bay			0.07								
	Sapp Prairie (digital)			0.04								
	Seagrove Lake			0.05								
5	SCRA			0.19	0.19	0	0.02 ---	0.05	0.05	0.04	1529	0.01
N=11, Daily							1 3		2			
1	Kingfisher Landing	1.00	0.37	1.32	1.27	0.39	--- 0.37		0.49		18283	0.11
	Durdin Prairie			1.10								
	Territory Prairie			1.39								

Table 2-7--continued.

Network, Estimate, Strata	Station	$\hat{S}_o^2$	$\hat{S}_{okl}$	$\hat{S}^2$	$\hat{S}_{oi}^2$	$\hat{S}_{okli}$	Between Strata Average Covariance		Stratum Area (ha)	W_i
2	SCFSP			1.35	1.35	0	0.49	---	2333	0.01
							0.45			
3	Double Lakes			0.90	0.84	0.31	0.37	0.45	139818	0.87
	Chase Prairie			1.08			---			
	Suwannee River			0.78						
	Coffee Bay			0.77						
	SCRA			1.13						
	Seagrove Lake			0.59						
	Sapp Prairie (digital)			0.64						
N=11, Biweekly							1	2		
1	Kingfisher Landing	0.11	0.06	0.16	0.11	0.06	---	0.07	149032	0.93
	Double Lakes			0.08						
	SCRA			0.20						
	Seagrove Lake			0.08						
	Chase Prairie			0.09						
	Coffee Bay			0.09						
	Sapp Prairie (digital)			0.07						
	SCFSP			0.11						
	Suwannee River			0.08						

Table 2-7--continued.

Network, Estimate, Strata	Station	$\hat{S}_o^2$	$\hat{S}_{okl}$	$\hat{S}^2$	$\hat{S}_{ol}^2$	$\hat{S}_{okli}$	Between Strata Average Covariance		Stratum Area (ha)	W_i
2	Durdin Prairie			0.09	0.13	0.11	0.07	---	11403	0.07
	Territory Prairie			0.16						
N=11, Monthly							1	2		
							3			
1	Double Lakes	0.07	0.03	0.06	0.07	0.03	---	0.03	15672	0.10
	Kingfisher Landing			0.10			0.04			
	Durdin Prairie			0.05						
	Territory Prairie			0.08						
2	Chase Prairie			0.05	0.05	0.03	0.03	---	143434	0.89
	Seagrove Lake			0.05			0.04			
	Coffee Bay			0.07						
	Sapp Prairie (digital)			0.04						
	SCFSP			0.06						
	Suwannee River			0.06						
3	SCRA			0.19	0.19	0	0.04	0.04	1354	0.01

Table 2-8. Relative, spatial, and total variances within the precipitation gauge network, network accuracy with various recorder densities, and suggested strata allocation of precipitation gauges.

Network, Variance, Accuracy	Daily Estimate, Method A	Daily Estimate, Method B	Daily Estimate, Method C	Biweekly Estimate, Method A	Biweekly Estimate, Method B	Biweekly Estimate, Method C	Monthly Estimate, Method A	Monthly Estimate, Method B	Monthly Estimate, Method C
N=14									
Relative Variance of Mean Rainfall	0.04	0.05	0.04	0.004	0.004	0.003	0.003	0.003	0.002
Spatial Variance of Mean Rainfall	0.49	0.38	0.38	0.06	0.06	0.06	0.04	0.03	0.03
Total Variance of Mean Rainfall	0.53	0.43	0.42	0.07	0.07	0.07	0.04	0.04	0.04
Network Accuracy:									
for β=0.10, α=0.05, N=	1735	2183	2183	18	170	170	16	141	141
for β=0.10, α=0.10, N=	1008	1269	1269	11	99	99	10	82	82
for β=0.10, α=0.15, N=	644	811	811	7	64	64	6	52	52
for β=0.10, α=0.20, N=	419	527	527	5	41	41	4	34	34
for N=14, α=0.05, β=	1.113	1.249	1.249	0.35	0.35	0.35	0.33	0.32	0.32
for N=14, α=0.10, β=	0.848	0.952	0.952	0.27	0.26	0.26	0.25	0.24	0.24
for N=14, α=0.15, β=	0.678	0.761	0.761	0.21	0.21	0.21	0.20	0.19	0.19
for N=14, α=0.20, β=	0.547	0.613	0.613	0.17	0.17	0.17	0.16	0.16	0.16
Strata Allocation of Gauges:									

Table 2-8--continued.

Network, Variance, Accuracy	Daily Estimate, Method A	Daily Estimate, Method B	Daily Estimate, Method C	Biweekly Estimate, Method A	Biweekly Estimate, Method B	Biweekly Estimate, Method C	Monthly Estimate, Method A	Monthly Estimate, Method B	Monthly Estimate, Method C
Strata 1	N=1 [a]			N=2			N=1		
Strata 2	N=6			N=5			N=7		
Strata 3	N=7			N=7			N=1		
Strata 4							N=5		
Strata 5							OMIT		
N=11									
Relative Variance of Mean Rainfall	0.06	0.06	0.05	0.004	0.005	0.004	0.004	0.003	0.002
Spatial Variance of Mean Rainfall	0.37	0.31	0.31	0.06	0.06	0.06	0.03	0.03	0.03
Total Variance of Mean Rainfall	0.42	0.37	0.36	0.07	0.06	0.06	0.04	0.03	0.03
Network Accuracy:									
for β=0.10, α=0.05, N=	247	2428	2428	20	193	193	16	105	105
for β=0.10, α=0.10, N=	142	1392	1392	11	111	111	9	60	60
for β=0.10, α=0.15, N=	90	884	884	7	71	71	6	39	39
for β=0.10, α=0.20, N=	59	572	572	5	46	46	4	25	25
for N=11, α=0.05, β=	1.499	1.49	1.49	0.42	0.42	0.42	0.37	0.31	0.31
for N=11, α=0.10, β=	1.135	1.13	1.13	0.32	0.32	0.32	0.28	0.23	0.23
for N=11, α=0.15, β=	0.904	0.90	0.90	0.25	0.25	0.25	0.23	0.18	0.18
for N=11, α=0.20, β=	0.727	0.72	0.72	0.20	0.20	0.20	0.18	0.15	0.15

Table 2-8--continued.

Network, Variance, Accuracy	Daily Estimate, Method A	Daily Estimate, Method B	Daily Estimate, Method C	Biweekly Estimate, Method A	Biweekly Estimate, Method B	Biweekly Estimate, Method C	Monthly Estimate, Method A	Monthly Estimate, Method B	Monthly Estimate, Method C
Strata Allocation of Gauges:									
Strata 1	N=2			N=10			N=1		
Strata 2	OMIT			N=1			N=9		
Strata 3	N=9						N=1		

[a] When recorders are redistributed among strata, no stratum should have < 2 stations so that covariances and within stratum variances can be estimated.

Figure 2-3. Recorder distribution for daily measurement of precipitation at 11 stations in Okefenokee Swamp.

Figure 2-4. Recorder distribution for daily measurement of precipitation at 14 stations in Okefenokee Swamp.

Figure 2-5. Recorder distribution for biweekly measurement of precipitation at 11 stations in Okefenokee Swamp.

Figure 2-6. Recorder distribution for biweekly measurement of precipitation at 14 stations in Okefenokee Swamp.

Figure 2-7. Recorder distribution for monthly measurement of precipitation at 11 stations in Okefenokee Swamp.

Figure 2-8. Recorder distribution for monthly measurement of precipitation at 14 stations in Okefenokee Swamp.

monthly intervals to estimate daily average rainfall; spatial variances are nearly equal with the random and stratified methods (Table 2-8), indicating that over longer intervals spatial variability of rainfall throughout the watershed is reduced.

Accuracy (β) for estimating daily precipitation to 3 mm with a 14-gauge network (α=0.20) is 0.55 (A) and 0.61 (B/C). This means there is a 30-45% probability that the daily precipitation will be measured within 3 mm of the true, daily volume. Bi-weekly and monthly estimates of daily average precipitation are more accurate ($\beta_{A, B/C}$=0.17 and $\beta_{A, B/C}$ =0.16, respectively). The similarity of accuracies of biweekly and monthly estimates of daily average precipitation calculated with methods A and B/C indicate that little improvement is gained by stratifying the network. The network density could be increased by 4 recorders distributed randomly to improve accuracy of daily average rainfall estimated with biweekly data to 90% (β=0.10, α=0.05), and by 2 recorders distributed randomly to improve accuracy of daily average rainfall estimated with monthly data to 90% (β=0.10, α=0.05). The network density would have to be increased to 1269 and 2735 stations for methods B/C and A, respectively, for the same accuracy of daily rainfall measurement within 3 mm, obviously an unmanageable system. Biweekly and monthly summaries of average daily precipitation require fewer stations to achieve the same level of statistical accuracy as for daily summaries. Therefore, the 14-gauge system should not be used to estimate rainfall day-by-day, but over longer intervals (bi-weekly or monthly) estimates from the network of average daily rainfall are appropriate. Random distribution of the gauges is sufficient, since watershed rainfall is uniform over the bi-weekly and monthly intervals and a minimal increase in network accuracy through

stratification would require a 10-fold increase in gauge density (Table 2-8). Little decrease in spatial or relative variance is apparent with stratification, although the current distribution among 3 strata with 2 gauges in strata 1, 5 in strata 2, and 7 in strata 3 is appropriate for a stratified network.

Removing 3 stations (Floyds, Sapling, and Cravens) from the network would reduce maintenance and management efforts, but the accuracy of rainfall estimates would decrease. The 3 stations selected for removal are difficult to access, but they are also isolated from other recorders. Relative and spatial variances of biweekly and monthly estimates of average daily rainfall are similar to those of the 14-gauge network (Table 2-8), indicating that when the data are summarized over longer intervals, heterogeneity in daily rainfall within the watershed is reduced. The spatial variance should be independent of the number of gauging stations if the watershed precipitation is homogeneous; an increase from 11 to 14 stations changes the estimate of daily spatial variance (Table 2-8), indicating that the differences in total variance of daily rainfall between the 11 and 14 gauge networks is partially due to the daily variability in rainfall in the watershed and also due to the isolation of the 11 gauges within the network. Accuracy (β) of the estimated daily precipitation measured within 3 mm with a 11-gauge network (α=0.20) is 0.73 (A) and 0.72 (B/C). Bi-weekly and monthly estimates of daily average precipitation are more accurate ($\beta_{A,\ B/C}$=0.20 and $\beta_{A,\ B/C}$=0.18, respectively). The similarity of accuracies of biweekly and monthly estimates of daily average precipitation calculated with methods A and B/C indicate that little improvement is gained by stratifying the network. However, great improvement occurs if the daily data

are summarized over biweekly or monthly intervals. Based on data from the 11 gauge network, a density of 20 recorders distributed randomly would be needed to improve accuracy of daily average rainfall estimated with biweekly data to 90% (β=0.10, α=0.05), and 16 recorders distributed randomly to improve accuracy of daily average rainfall estimated with monthly data to 90% (β=0.10, α=0.05). The added effort in maintaining the additional 3 recorders in the 14 gauge network slightly improves the biweekly and monthly estimates of average daily data, but they are not sufficient to provide accurate daily data estimates.

Discussion of Precipitation Network Analysis

The precipitation gauge network is intended to provide daily rainfall estimates throughout the swamp. This assessment of network accuracy indicates that the network density is sufficient to provide estimates of daily rainfall within 3 mm of actual precipitation volume if the daily estimates are averaged over intervals of at least 14 days. The accuracy of these estimates (86-87%) decreases at finer temporal resolution, because of the spatial variability in daily precipitation. If daily measurements are used without averaging over longer intervals, the accuracy in area rainfall prediction to within 3 mm is 39-45%. A network of 11 stations will provide biweekly and monthly estimates of daily rainfall with an accuracy of 78-80%; however, the 3 stations (Sapling and Floyds Prairies, and Cravens Hammock) removed due to inaccessibility actually alter stratum delineations. Addition of 4 recorders to the existing network would permit biweekly and monthly estimation of daily average rainfall within 3 mm, with an accuracy of 90% (β=0.10, α=0.05). Repair of the existing gauges not used in this analysis (Sill, Gannett

Lake, Moonshine Ridge, Honey Prairie) and implementation in the recorder network would achieve this goal.

Estimation of Missing Precipitation Data

The swamp hydrology model requires bi-weekly precipitation totals for each 500X500 m cell throughout the swamp. Swamp precipitation recorders provided a partial daily rainfall record, due to malfunctioning recorders; estimates of missing data were needed to calculate average bi-weekly precipitation for the model. The database of original and estimated biweekly precipitation totals were then interpolated using the ARCGRID KRIGING procedure (circular model) or the ARC TINNING (quintic) and ARC GRID procedures. The interpolated grids provided precipitation data for the hydrology model (see Chapter 3).

Correlation and simple linear regression procedures were used to estimate missing bi-weekly totals for each recorder. Waycross, GA, data were used to estimate swamp rainfall coverage at recorder sites during 1930-1979. Comparisons for the best correlations and regressions were calculated among local recorder pairs (the nearest 1-3 stations, using relationships in sequence of highest to lowest r_{adj}^2 until a complete bi-weekly dataset resulted) for the 1980-1993 missing data. Precipitation data collected at Nahunta, Homerville, Folkston SW, and Waycross WSMO, GA, NOAA weather stations were included in these precipitation calculations. Only non-regressed, original recorder data were used in the correlation and regression calculations. Several regression relationships were necessary for each station to ensure complete data coverage during the

interval (Table 2-9). All regression pairs met assumptions of linearity, independence and normality of residuals, independence of data, and non-autocorrelated residuals (Durbin-Watson D) (Myers 1990).

Estimation of Evapotranspiration, Inflow, and Outflow Data

The swamp hydrology model requires estimates of biweekly, surface water inflow, outflow, and evapotranspiration. The outflow points for surface water included in the swamp hydrology model were the Suwannee River, Cypress Creek, and Sweetwater Creek, near Fargo, GA, and the St. Marys River near Moniac, GA (Figure 2-9). Data retrieved from USGS gauges that measured daily Suwannee and St. Marys Rivers flow rates for 1930-1993 provided biweekly estimates of surface outflow volume for the hydrology model and analysis of the sill's effects on swamp hydrology. The St. Marys River gauge at Moniac, GA, was dismantled in 1989 and reinstalled in 1991; missing data for this station for 1989-1991 were estimated with regressions with the St. Marys, MacClenney, FL, USGS flow gauge, or the Suwannee River, Fargo, GA, flow gauge (Table 2-10). Missing Suwannee River flow data were estimated from regression relationships with the St. Marys River gauges at Moniac, GA, and Macclenney, FL. Flow gauges were not installed at Cypress and Sweetwater Creeks. Measurements of biweekly flow volume at these stations were estimated from regression relationships established between the creek water depth and Suwannee River flow recorded daily during 1991-1993 (Table 2-10). Only non-regressed, original recorder data were used in the

Table 2-9. Best correlation pairs and regression equations used to estimate missing precipitation recorder data for use in HYDRO-MODEL, during 1930-1993.

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
1930-1947			
Sapp Prairie (digital)	Waycross	0.2775	$y = 0.617487x + 0.491895$
Craven's Hammock	Waycross	0.3632	$y = 0.469907x + 2.585811$
Durdin Prairie	Waycross	0.2439	$y = 2.31721x^{1/2} - 0.141917$
Coffee Bay	Waycross	0.3805	$y = 0.508594x + 1.15652$
1930-1948			
SCRA	Waycross	0.3849	$y = 0.657773x + 2.176066$
Folkston SW	Waycross	0.4478	$y = 0.699435x + 1.629737$
Moonshine Ridge	Waycross	0.2527	$y = 0.630105x + 1.239003$
1930-1956			
Nahunta	Waycross	0.5238	$y = 0.816304x + 1.122031$
Homerville	Waycross	0.5676	$y = 0.806905x + 1.197628$
1930-1978			
Waycross WSMO	Waycross	0.7091	$y^{1/2} = 0.18902x + 1.002779$
1930-1979			
Soldier's Camp	Waycross	0.2629	$y = 0.963607x + 0.775384$
Suwannee Creek (chart)	Waycross	0.1818	$y = 1.207899x + 0.101984$
Territory Prairie	Waycross	0.2374	$y = 0.488879x + 1.230789$
Suwannee River	Waycross	0.5141	$y = 0.56549x + 2.114985$
Floyd's Prairie	Waycross	0.4429	$y = 0.598386x + 1.885058$
Honey Prairie	Waycross	0.4006	$y = -0.2606x + 4.381847$

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
1930-1980			
SCFSP	Waycross	0.4609	y = 0.69817x + 1.678838
1948-1979			
Coffee Bay	SCRA	0.5761	y = 0.644515x + 0.257361
Durdin Prairie	Folkston	0.7483	y = 0.6527x + 0.796215
Cravens Hammock	SCRA	0.5813	y = 0.747346x + 0.449443
1948-1981			
Moonshine Ridge	SCRA	0.3452	y = 0.636717x + 0.691347
1948-1993			
Sapp Prairie (digital)	SCRA	0.9185	y = 0.92291x - 0.02865
1979-1991			
Coffee Bay	SCFSP	0.6228	y = 0.751514x + 0.126923
Honey Prairie	Seagrove Lake	0.7839	y = 1.188659x - 0.430333
Durdin Prairie	Territory Prairie	0.8406	y = 0.785827x + 1.644113
Suwannee River	SCFSP	0.8498	y = 0.84687x + 0.233137
Floyd's Prairie	SCFSP	0.7686	y = 0.938372x + 0.279866
Sapp Prairie (digital)	Seagrove Lake	0.5791	y = 0.568588x + 1.84186
Sapling Prairie	Chase Prairie	0.2712	y = 0.435358x + 2.689235
Craven's Hammock	SCFSP	0.4296	y = 0.684317x + 1.287402
1980-1982			
Kingfisher Landing	Suwannee Creek (chart)	0.4003	y = 0.446332x + 2.128122

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
Double Lakes	Suwannee Creek (chart)	0.6166	y = 0.61941x + 1.128997
Sill (Brown Trail)	Suwannee Creek (chart)	0.5880	y = 0.44801x + 2.326436
Sapp Prairie (chart)	Soldier's Camp	0.2685	y = 0.504175x + 0.626725
1980-1993			
SCFSP	Chase Prairie	0.4123	y = 0.715778x + 2.776936
Territory Prairie	Chase Prairie	0.5189	y = 0.862786x + 0.831206
Chase Prairie	SCFSP	0.4123	y = 0.581559x + 0.441311
Double Lakes	Chase Prairie	0.4150	y = 0.591811x + 1.345497
Kingfisher Landing	Double Lakes	0.3453	y = 0.618564x + 1.263495
Seagrove Lake	Territory Prairie	0.3489	y = 0.537173x + 0.605698
Sill (Brown Trail)	Soldier's Camp	0.5443	y = 0.590046x + 0.394465
Soldier's Camp	Sill (Brown Trail) Sapp Prairie (chart) Seagrove Lake	0.5443 0.2685 0.2581	y = 0.967946x + 2.008823 y = 0.577914x + 2.976061 y = 0.502014x + 2.757349
Suwannee Creek (chart)	Double Lakes Sill (Brown Trail)	0.6266 0.5880	y = 1.00928x + 0.384732 y = 1.34424x - 1.249998
Moonshine Ridge	SCFSP	0.4274	y = 0.776344x + 0.62422
1982-1993			
Gannett Lake	SCFSP	0.4271	y = 0.57035x + 0.313958
Sill (Brown Trail)	SCFSP	0.4680	y = 0.716572x - 0.29646
Sapp Prairie (chart)	Sill (Brown Trail)	0.2149	y = 0.519188x + 0.261563
1992-1993			

Interval and Predicted Station (Y)	Predictor Station (X)	r^2_{adj} [a]	Regression Equation to Estimate Y
SCFSP	Suwannee River	0.8498	y = 0.954722x + 0.585187
	Floyd's Prairie	0.7686	y = 0.938372x + 0.27866
Durdin Prairie	Territory Prairie	0.8406	y = 1.074218x - 0.967435
	Chase Prairie	0.8346	y = 0.872464x - 0.712295
	Double Lakes	0.4802	y = 0.658392x + 0.355303
	Kingfisher Landing	0.5398	y = 0.951845x - 0.520653
	Gannett Lake	0.1848	y = 0.246431x + 0.440111
Honey Prairie	Seagrove Lake	0.7839	y = 1.188659x - 0.430333
Sapp Prairie (digital)	Suwannee River	0.7424	y = 0.822689x + 0.610583
	Craven's Hammock	0.7411	y = 0.944445x + 0.339577
	Floyd's Prairie	0.7312	y = 0.646029x + 0.819186
	Honey Prairie	0.6868	y = 0.872658x + 0.99355
	Coffee Bay	0.6544	y = 0.776927x - 0.036708
	Seagrove Lake	0.5791	y = 1.045958x - 0.536715
Suwannee River	Sapp Prairie (digital)	0.7424	y = 0.822689x + 0.610583
	Floyd's Prairie	0.7026	y = 1.027007x + 1.139322
	Sill (Brown Trail)	0.4215	y = 0.727799x + 0.724884
Territory Prairie	Durdin Prairie	0.8406	y = 0.785827x + 1.644113
Floyd's Prairie	Durdin Prairie	0.7536	y = 0.768902x + 0.674328
Craven's Hammock	Coffee Bay	0.7023	y = 0.777602x + 0.294183
	Sapling Prairie	0.5828	y = 0.608385x + 1.188687
SCRA	Craven's Hammock	0.5813	y = 0.747346x + 0.449443
Coffee Bay	Craven's Hammock	0.7023	y = 0.910215x + 1.379420
	Sapling Prairie	0.5828	y = 0.777694x + 0.189880
Seagrove Lake	Honey Prairie	0.7839	y = 1.188659x - 0.430333

[a] All regression relationships were significant at $P \leq 0.05$.

Figure 2-9. Recorder locations for daily measurement of air temperature and surfacewater inflows and outflows in Okefenokee Swamp.

Table 2-10. Regression relationships used to estimate river and creek outflow rates from Okefenokee Swamp during 1930-1993.

Creek or River	**Predictor Measure**	**Predicted Measure**	r^2_{adj}	**P**	**Regression Equation**	**Condition of Flow = 0**
St. Marys River, Moniac	St. Marys, MacClenney Flow	St. Marys, Moniac Flow	0.8094	0.0001	$y = 0.202734x + 0.032221$	flow < 0.93 m^3/sec
Cypress Creek	Suwannee, Fargo Flow$^{1/2}$	Cypress Staff	0.8033	0.0001	$y = 0.065906x^{1/2} + 33.845825$	staff < 33.8 m
Cypress Creek	Suwannee Fargo, Flow	Cypress Flow	0.6762	0.0001	$y = 0.153409x + 0.288727$	flow < 1.88 m^3/sec
Sweetwater Creek	Cypress Creek Flow	Sweetwater Flow			Sweetwater Flow= (0.25)*Cypress Creek Flow	

regression calculations. All regression pairs met assumptions of linearity, independence and normality of residuals, independence of data, and non-autocorrelated residuals.

The hydrology model required biweekly surface water inflow from creeks along the swamp perimeter. Creek flow into the swamp is significant only along the northwest boundary, accounting for an estimated 20% of the swamp annual water budget (Blood 1981, Rykiel 1977). Water depths were measured on permanently installed staff gauges in 7 creeks (Bear Branch, Cane Creek, Gum Swamp, Suwannee Creek, Greasy Branch, Surveyor's Creek, Black River) every 4-6 weeks during 1991-1995 to establish water depth relationships with the Suwannee River (Figure 2-9). Creek flow rate was also measured with a General Oceanics, Inc., flow gauge, converted to flow volume based on creek dimensions measured at the recording station, and regressed with concurrently collected staff data to relate creek water depth to estimated creek flow volume (Table 2-11). Regression relationships between creek water depth and Suwannee River flow were used to extend the creek water depth estimates back to 1941 (Table 2-12); the estimated creek water depths were then converted to estimated creek flow volumes using these regression relationships. All regression pairs met assumptions of linearity, independence and normality of residuals, independence of data, and non-autocorrelated residuals.

Approximately 80% of the water that leaves the swamp does so through evapotranspiration, or ET (Yin and Brook 1992a, Yin 1990, Hyatt 1984, Blood 1981, Rykiel 1977). This parameter was not measured directly in this study but was estimated for the hydrology model database using Thorthwaite's equation for monthly potential

Table 2-11. Estimating creek flow into Okefenokee National Wildlife Refuge using water depth estimates from creek staffs.

Creek	Predictor Measure	Predicted Measure	r^2	P	Regression Equation	Condition of Flow = 0
Bear Branch	Creek Staff$^{1/2}$	Creek Flow	0.8752	0.0125	$y = 41.440921x^{1/2} - 22.185188$	Staff $\leq$ 0.54
Black River	Creek Staff	Creek Flow	0.2160	0.1643	$y = 11.176664x - 8.789537$	Staff $\leq$ 0.79
Cane Creek	Creek Staff	Creek Flow	0.8464	0.0001	$y = 4.85548ax - 1.493456$	Staff $\leq$ 0.31
Greasy Branch	Creek Staff	Creek Flow	0.9387	0.0206	$y = 16.439612x - 14.005681$	Staff $\leq$ 0.85
Gum Swamp	Creek Staff	Creek Flow	0.3381	0.0355	$y = 6.640242x - 6.153242$	Staff $\leq$ 0.93
Suwannee Creek	Creek Staff	Creek Flow	0.8854	0.0001	$y = 21.586097x - 25.360366$	Staff $\leq$ 1.17
Surveyor's Creek	Creek Staff	Creek Flow	0.6250	0.0696	$y = 1.938568x - 2.491591$	Staff $\leq$ 1.29

Table 2-12. Regression relationships used to estimate water depths at staffs in northwestern creeks from flow measurements at the Suwannee River-Fargo gauge.

Creek	Predictor Measure	Predicted Measure	r^2	P	Regression Equation
Bear Branch	River Flow	Creek Staff	0.3484	0.0552	$y = 0.005794x + 0.291364$
Cane Creek	River Flow	Creek Staff	0.6773	0.0001	$y = 0.01616x + 0.085627$
Gum Swamp	River Flow	Creek $Staff^{1/2}$	0.4739	0.0019	$y = 0.074380x^{1/2} + 0.546947$
Suwannee Creek	River Flow	Creek $Staff^{1/2}$	0.7270	0.0001	$y = 0.111256x^{1/2} + 0.645043$
Greasy Branch	River Flow	Creek $Staff^{1/2}$	0.7187	0.0001	$y = 0.88629x^{1/2} + 0.063674$
Surveyor's Creek	River Flow	Creek $Staff^{1/2}$	0.7434	0.0001	$y = 0.126597x^{1/2} + 0.409234$
Black River	River Flow	Creek $Staff^{1/2}$	0.7875	0.0001	$y = 0.076624x^{1/2} + 0.202671$

evapotranspiration (Thornthwaite 1948). The relationship creates a ratio of mean monthly air temperature and heat index as follows:

$$PE = (1.62)b(10T/I)^a ,$$

where
PE = monthly potential evapotranspiration (cm)
b = monthly latitude coefficient to account for seasonal radiation (Table 2-13)
T= monthly average daily temperature °C
$a = 67.5 \times 10^{-8}I^3 - 77.1 \times 10^{-6}I^2 + 0.0179I + 0.492$

I = heat index = $\sum_{m=1}^{12}(t_m/5)^{1.51}$, where m=monthly periods, t=mean monthly air temperature, °C.

Table 2-13. Monthly latitude adjustment to account for seasonal radiation in calculation of Thornthwaite's PE (from Thornthwaite (1948)).

January	February	March	April	May	June
0.90	0.87	1.03	1.08	1.18	1.17
July	August	September	October	November	December
1.20	1.14	1.03	0.98	0.89	0.88

Daily air temperatures were recorded for various intervals at 6 NOAA weather stations around the swamp (Figure 2-9). Regression relationships between these stations were used to estimate missing daily average temperature, which were used in the estimate of PE (Table 2-14). Mitsch and Gosselink (1986) suggest that in wetland environments, potential evapotranspiration is nearly equivalent to actual evapotranspiration since water availability is rarely limited. M. Focazio (USGS, unpublished data) estimated that

Table 2-14. Regression equations used to estimate missing daily maximum air temperature at NOAA weather stations around Okefenokee National Wildlife Refuge.

Predicted Station	Data Interval	Predictor Station	r^{2a}	Regression Equation
Homerville	1930-1955 1956-1993	W4NE Folkston	0.9740 0.9882	$y = 0.986729x + 0.173426$ $y = 0.918883x - 1.808971$
Folkston	1930-1947 1948-1993	W4NE Homerville	0.9240 0.9882	$y = 1.093731x - 0.887017$ $y = 1.075527x - 3.057219$
Fargo (SCFSP)	1930-1981 1982-1993	W4NE Folkston	0.9173 0.9735	$y = 1.07418x - 0.831709$ $y = 0.960154x - 2.714077$
Nahunta	1930-1955 1956-1993	W4NE Folkston	0.9691 0.9679	$y = 0.967064x + 0.409845$ $y = 0.567515x + 16.866641$
WSMO	1930-1978 1979-1993	W4NE Homerville	0.9180 0.9820	$y = 1.0968x - 1.034505$ $y = 1.01434x - 1.202566$
W4NE	1930-1993	Homerville	0.9793	$y = 1.10042x - 2.289395$

[a] All regression relationships are significant at $P = 0.0001$.

Thornthwaite's PE underestimates actual evapotranspiration in cattail (*Typha* spp.) swamp up to 37%; a comparable adjustment to the calculated ET values for Okefenokee Swamp was made in the hydrology model (see Chapter 3) to refine model output. Yin and Brook (1992a) also found Thornthwaite's PE to be well-correlated with actual evapotranspiration rates in the swamp. The monthly ET volume was halved to provide biweekly volumes for the hydrology model. Biweekly estimates were interpolated among recorder stations using ARCINFO's tinning (quintic) procedure to create biweekly ET surfaces, and gridded at 500x500 m cell resolution for use in the hydrology model.

Swamp Basin Delineation and Characterization

Water level data recorded at gauges during 1980-1995 illustrate the spatial connectivity as well as regional variabilities of the Okefenokee Swamp hydrologic environment (Table 2-2). Highest water elevations were recorded in the North and Northeast (Double Lakes, Kingfisher Landing, Durdin Prairie, Sapling Prairie), where peat surface elevations are highest, and in Honey Prairie, where a northwest to southeast peat surface ridge runs between Honey and Blackjack Islands. Lowest water surface elevations were recorded in the Southwest drainages (Suwannee River, Sill, Sweetwater Creek, Cypress Creek) and St. Mary's River basin (Soldiers Camp). Greatest variability in water surface elevation occurred in high flow areas, such as the creeks and tributaries to the Suwannee and St. Mary's Rivers (Figure 2-10). During 1992-1995 water surface elevations at the Sill, Suwannee River, Craven's Hammock, Cypress Creek, and Suwannee Creek changed 2.16-1.06 m. Greatest changes in water surface elevations in a day were recorded at Suwannee, Sweetwater, and Cypress Creeks, the Sill, Craven's Hammock, and Territory Prairie (+0.40 - +0.29 m). All of these stations are located in areas of channelized flow. Territory Prairie experiences a drop towards Chase Prairie of 0.6 m in peat surface elevation in the area around the recorder. The change in elevation localizes the area's water flow into the maintained canoe trail near the recorder station. Prairies, lakes, and canals had the smallest high to low water level ranges. Maximum water surface elevation changes in Chase, Durdin, and Honey Prairies, Double Lakes, Moonshine Ridge ditch, and Kingfisher Landing canal ranged 0.31- 0.45 m; daily

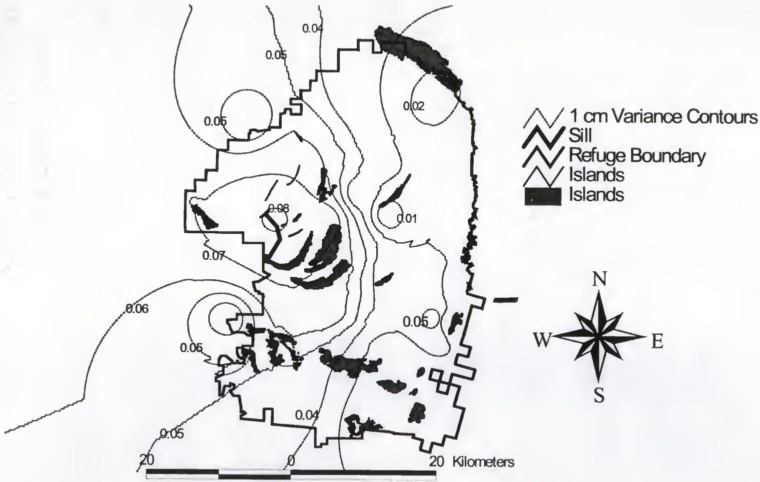


Figure 2-10. Variance contours for water depths recorded daily at locations in the Okefenokee Swamp during 1992-1995.

changes were generally less than a centimeter. There are 5 "basins" represented by the spatial variability of the swamp hydrology (Figure 2-11, Table 2-2). Each of these areas follows the overall seasonal trends in water surface elevation, but the magnitude of these trends varies among the basins (Figure 2-12). Greatest seasonal and annual variability in water surface elevation occurs in the northwestern region; water surface elevation in this area is probably controlled by seasonal rainfall, primarily because much of the water is contributed by streams in the watershed to the west of the swamp. In contrast the least seasonal and annual variability in water surface elevation occurs in the Northeast. This may be due to groundwater inflows or restricted outflow creating a perched water surface. The central region has intermediate variability. Most of the water in this region is contributed by precipitation, and water surface elevation declines rapidly during periods of high evaporative demand. There may be some groundwater exchange in this area through springs, although this component of the water budget may be relatively minor, and probably originates in the surficial aquifer (Rykiel 1984, 1977, Patten and Matis 1984, 1982). The Southeast and Southwest basins are somewhat hydrologically isolated from the rest of the swamp by a surface ridge created by large islands (Blackjack, Mitchell, Soldiers Camp, Honey, Billy, Pocket). The southwest basin contributes to the Suwannee River outside of the refuge boundary, and the Southeast basin forms the headwaters of the St. Mary's River. These areas show intermediate fluctuations of the central region, and variability like the northwestern region at the basin low points (Soldiers Camp in the Southeast and Cypress and Sweetwater Creeks in the Southwest). The role of precipitation, evapotranspiration, inflows, and outflows in

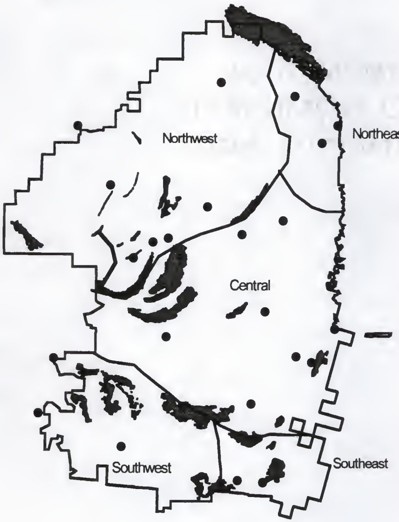


Figure 2-11. Water level recorder locations and hydrologic basins in Okefenokee Swamp.

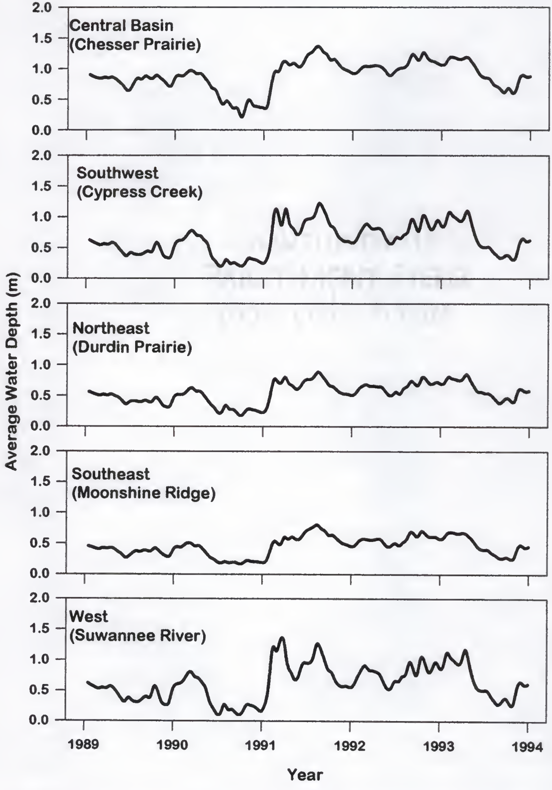


Figure 2-12. Trends in water level fluctuations in the Okefenokee Swamp hydrologic basins.

controlling swamp water depth varies with the basin. These relationships are explored in the hydrology model discussion in Chapter 3.

Approximately 80% of the swamp water budget is contributed by precipitation and removed by evapotranspiration (Yin 1990, Hyatt 1984, Blood 1981, Rykiel 1977). The effects of these processes on swamp water level vary seasonally. Evapotranspiration demands are unimodal, with a peak during May-August (Figure 2-13). Precipitation peaks during June-September and again during January-March (Figure 2-14). The higher precipitation volume during June-September does not usually result in high water levels because of the evapotranspiration demand; water levels are more likely to rise with the increased precipitation volume in January-March, when evapotranspiration demands are lowest. Evapotranspiration rates are not uniform across the swamp, but reflect differences in vegetation composition; evapotranspiration has a greater effect on swamp water level fluctuations in the eastern swamp than in the west (see Chapter 3). River outflows and creek inflows account for approximately 10-30% of the overall swamp water budget (Blood 1981, Rykiel 1977). Fluctuations in inflows and outflows follow those of precipitation, with biannual peaks in February-April and August-October (Figures 2-15 and 2-16). Water entering the swamp via creeks and rivers impacts the western swamp, although minimal surficial input occurs from streams along the eastern perimeter (Brook and Hyatt 1985, Hyatt 1984, Hyatt and Brook 1984, Rykiel 1984, 1977)(also see Chapter 3). Groundwater exchange is estimated at 3-5% of the swamp water budget; the sources, variability, and extent of this component are unknown (Brook and Hyatt 1985, Hyatt 1984, Hyatt and Brook 1984, Rykiel 1984, 1977).

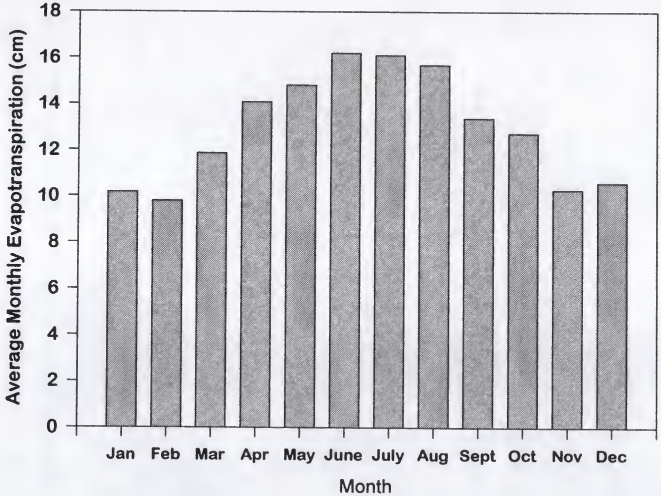


Figure 2-13. Monthly average evapotranspiration estimated in the Okefenokee Swamp area during 1930-1993.

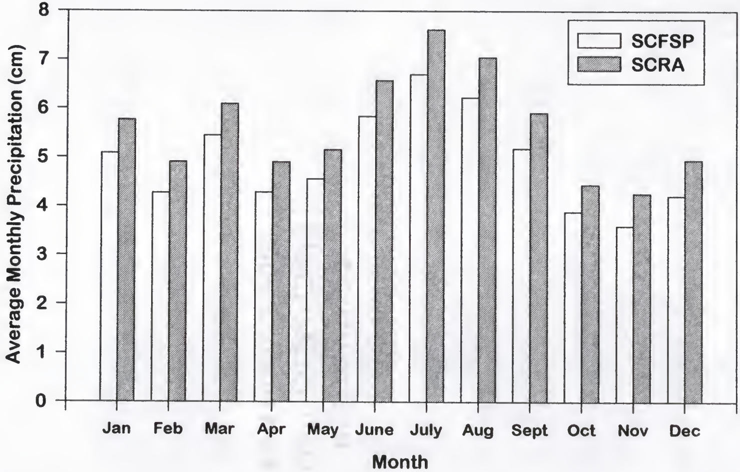


Figure 2-14. Average monthly precipitation estimated at sites in the Okefenokee Swamp area during 1930-1993.

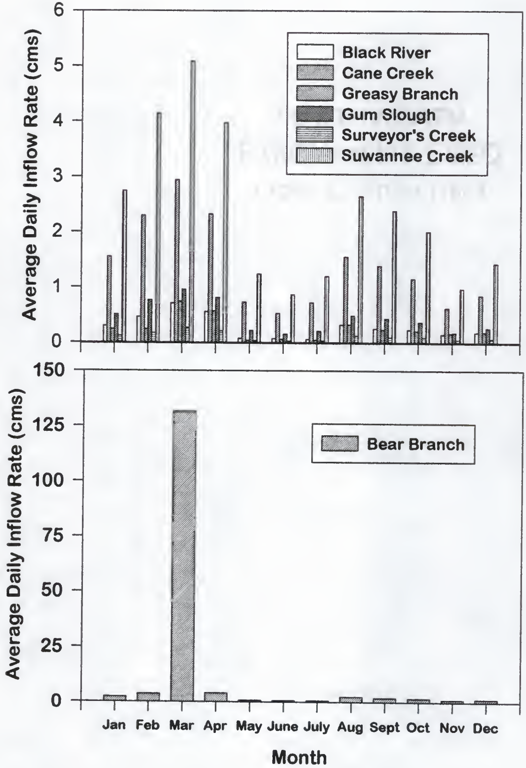


Figure 2-15. Average daily inflow estimated for northwestern creeks entering Okefenokee Swamp during 1930-1993.

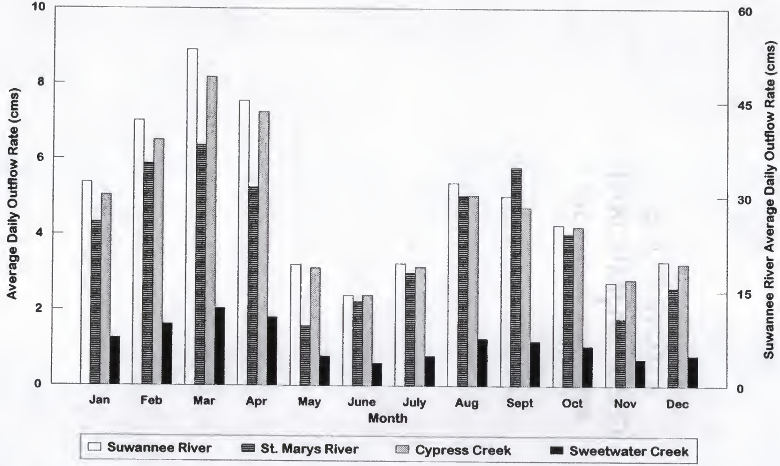


Figure 2-16. Average daily outflow estimated for creeks and rivers exiting Okefenokee Swamp during 1930-1993.

Effects of the Suwannee River Sill on Swamp Water Level Conditions

Changes in water surface elevation that have occurred at SCRA and SCFSP during 1941-1995 suggest effects of the Suwannee River sill on swamp hydrology; recorder data from these stations provide an indication of the sill's effects independent of results from the swamp hydrology model. The swamp hydrology model presents a more complete picture of the sill's spatial effects; however, the data collected at the SCRA and SCFSP gauges are the only original data available from the pre-sill period. Pre-sill starting water depths for the swamp hydrology model are based on SCFSP and SCRA gauges and their regression relationships with other recorders, under with-sill conditions. The effects of the sill discussed here are calculated from pre- and with-sill data collected only at the SCRA and SCFSP gauges. Effects estimated by the swamp hydrology model at other recorder stations are discussed in Chapter 3. Comparisons between pre- and with-sill intervals are with t-tests; variances are compared with F-tests. Comparisons among decades are with analysis of variance and Tukey's test for differences among means. Flow and precipitation data were normalized with log transformations.

The sill has affected the swamp hydrologic environment, although its effects vary with distance from the structure (Chapter 3). Although Yin and Brook (1992b) and Yin (1990) reported that discharge volume from the Suwannee River decreased and St. Marys flow variability increased after sill construction, their results may have reflected a data record that did not include a recent period of low rainfall, and insufficient topographic information (see topography map development and discussion, this chapter). An

additional 7 years (1987-1993) of with-sill Suwannee River and St. Marys River flow data recorded at Fargo, GA, and Moniac, FL, respectively, were included in my analyses. Log-transformed, biweekly total flows measured at these stations during pre-sill (1930-1959) and with-sill (1960-1993) intervals show increased biweekly flow volume at both stations in the with-sill period ($P=0.0001$) (Table 2-15). Extension of the flow record to 1993 also suggests that variability of the Suwannee River flow decreased during the with-sill interval ($P<0.0001$), whereas variability of the St. Marys River flow did not change with installation of the sill ($P=0.1452$). Yin and Brook (1992b) and Yin (1990) attributed the increased flow volume and decreased flow variability recorded at the St. Marys River to the sill; they hypothesized that the impounding effect of the sill was causing these changes. The changes in flow volume and variability at the St. Marys and Suwannee River gauges indicated in this study most likely reflect concurrent changes in rainfall patterns, not sill-induced modifications of water flow within the swamp. Although t-test comparisons of log-transformed precipitation volumes recorded at SCFSP and SCRA showed no differences in pre- and with-sill biweekly totals, variability of rainfall volume was slightly higher at the SCRA recorder following sill construction, and January precipitation totals were higher and September totals lower at both stations during the with-sill period (Table 2-16). Suwannee and St. Marys River flow volumes were also higher in January following sill construction (Table 2-15). These higher flows may have resulted in part from changes in air temperatures and evaporative demands; pre-sill estimated evapotranspiration volumes were higher at most NOAA weather stations in the watershed during all months except May, July, September, and November

Table 2-15. Comparison of flow rates measured at the Suwannee River (Fargo) and the St. Marys River (Moniac) gauges before and after construction of the Suwannee River Sill, during 1930-1993.

Interval	Station	Pre-Sill Mean Flow Rate (cms)	With-Sill Mean Flow Rate (cms)	Pre-Sill Flow Rate Variance (cms)	With-Sill Flow Rate Variance (cms)	Comparison of Means P > t	Comparison of Variances P > F
1930-1993	St. Marys River	1.16	1.56	21.20	15.56	0.001	0.1452
	Suwannee River	9.84	12.04	31.46	12.40	0.0236	<0.0001
January	St. Marys River	1.12	2.95	16.57	4.97	0.0004	0.0273
	Suwannee River	12.47	15.27	17.94	8.12	0.4694	0.2048
February	St. Marys River	1.49	4.42	22.32	4.51	0.0001	0.0043
	Suwannee River	13.21	33.86	10.59	3.75	0.0002	0.0219
March	St. Marys River	1.75	4.22	23.15	3.35	0.0012	0.0001
	Suwannee River	19.73	41.33	8.32	2.94	0.0015	0.0076
April	St. Marys River	1.25	1.94	21.97	9.04	0.1236	0.1788
	Suwannee River	19.90	27.42	7.63	3.98	0.1658	0.1258
May	St. Marys River	0.38	0.60	8.32	16.34	0.1155	0.2856
	Suwannee River	7.10	11.15	9.96	5.17	0.0701	0.1825
June	St. Marys River	0.74	0.51	17.35	39.02	0.2649	0.3500
	Suwannee River	3.79	6.82	20.32	9.16	0.0410	0.2227
July	St. Marys River	1.77	1.10	13.68	13.07	0.1107	0.9386
	Suwannee River	7.50	9.56	20.38	7.41	0.3840	0.1052

Table 2-15--continued.

Interval	Station	Pre-Sill Mean Flow Rate (cms)	With-Sill Mean Flow Rate (cms)	Pre-Sill Flow Rate Variance (cms)	With-Sill Flow Rate Variance (cms)	Comparison of Means P > t	Comparison of Variances P > F
August	St. Marys River	2.18	2.53	16.47	6.85	0.5912	0.1426
	Suwannee River	11.28	12.17	55.96	17.05	0.8162	0.1653
September	St. Marys River	2.09	2.45	22.08	14.83	0.5995	0.5875
	Suwannee River	13.60	11.87	16.08	14.25	0.6428	0.8571
October	St. Marys River	1.48	0.92	29.77	22.08	0.1496	0.7169
	Suwannee River	10.10	5.87	247.54	17.50	0.1430	0.0100
November	St. Marys River	0.75	0.67	8.79	5.48	0.6842	0.3402
	Suwannee River	6.93	3.97	78.73	8.45	0.0929	0.0052
December	St. Marys River	0.68	1.29	17.18	8.70	0.0244	0.2847
	Suwannee River	5.72	6.45	141.75	11.84	0.7283	0.0065

Table 2-16. Comparison of pre-sill and with-sill biweekly total precipitation volumes at SCFSP and SCRA during 1930-1995.

Month	Station	Pre-Sill Biweekly Mean Total Precipitation (cm)	With-Sill Biweekly Mean Total Precipitation (cm)	Pre-Sill Biweekly Total Precipitation Variance (cm)	With-Sill Biweekly Total Precipitation Variance (cm)	Comparison of Means $P > t$	Comparison of Variances $P > F$
January	SCFSP	3.45	4.95	1.24	1.38	0.0002	0.1177
	SCRA	4.11	5.72	1.20	1.31	0.0002	0.1199
February	SCFSP	3.82	3.92	1.24	1.25	0.7470	0.9537
	SCRA	4.51	4.40	1.20	1.32	0.7807	0.1148
March	SCFSP	4.33	4.61	1.29	1.41	0.5198	0.2671
	SCRA	5.08	5.37	1.25	1.32	0.5362	0.3567
April	SCFSP	3.86	3.56	1.28	1.34	0.3993	0.5369
	SCRA	4.56	4.22	1.23	1.31	0.3927	0.3193
May	SCFSP	3.84	3.64	1.31	1.56	0.6208	0.0599
	SCRA	4.54	4.50	1.26	1.40	0.9280	0.1546
June	SCFSP	4.91	5.50	1.29	1.29	0.2185	0.9920
	SCRA	5.70	6.28	1.25	1.25	0.2579	0.9654
July	SCFSP	6.31	6.11	1.17	1.21	0.6621	0.4148
	SCRA	7.21	6.87	1.14	1.17	0.4870	0.5670
August	SCFSP	5.40	5.67	1.27	1.25	0.5851	0.7925
	SCRA	6.22	6.64	1.23	1.19	0.4315	0.5297

Table 2-16--continued.

Month	Station	Pre-Sill Biweekly Mean Total Precipitation (cm)	With-Sill Biweekly Mean Total Precipitation (cm)	Pre-Sill Biweekly Total Precipitation Variance (cm)	With-Sill Biweekly Total Precipitation Variance (cm)	Comparison of Means P > t	Comparison of Variances P > F
September	SCFSP	4.92	3.93	1.44	1.29	0.0256	0.1797
	SCRA	5.73	4.50	1.37	1.33	0.0151	0.7036
	SCFSP	3.17	3.07	1.40	1.41	0.7641	0.9351
October	SCRA	3.82	3.73	1.32	1.30	0.8011	0.7772
November	SCFSP	2.89	3.12	1.25	1.39	0.4366	0.1440
	SCRA	3.50	3.77	1.20	1.34	0.4167	0.0738
December	SCFSP	3.45	3.83	1.24	1.25	0.2097	0.8380
	SCRA	4.11	4.59	1.19	1.21	0.1555	0.7861

(Table 2-17). It is also likely that the increased river flow is due to greater flows in the creeks entering the Northwest swamp during this period, since creek flow would also be affected by changing evapotranspiration and precipitation rates in the watershed. Channelization and logging in the northwestern creek watersheds may also be affecting flow volumes and rates in the Suwannee River.

Water levels at SCFSP and SCRA also changed following sill construction. Overall water depths were lower and more variable before the sill was built; this trend occurred during the growing and non-growing seasons, although the decreased variability in growing season water level at SCFSP was not significant following sill construction (Table 2-18). The smallest change in water depth occurred in October-November at SCFSP and September-December at SCRA, and variability decreased mainly during October-January at SCFSP and November-March at SCRA. At SCFSP water depths were higher during 10 months, and variability was lower during 4 months with the sill in place, but only December and January had both higher water levels and lower variability. At SCRA water levels were higher during 8 months, and variability was lower during 5 months with the sill in place, but only January-March had both higher water levels and lower variability. These decreases in water level variabilities correspond to increased and more variable non-growing season (primarily January) precipitation recorded at SCFSP and SCRA while the sill was in operation (Table 2-16).

Trends in biweekly rainfall totals exist among decades, although the differences among decades are not statistically significant (Table 2-19). Highest average biweekly precipitation totals recorded at SCRA and SCFSP occurred during the 1960s and 1970s,

Table 2-17. Comparison of evapotranspiration (ET) estimates in the Okefenokee Swamp area before and after Suwannee River Sill construction, 1930-1993.

Month	Station	Pre-Sill Monthly Mean ET (cm)	With-Sill Monthly Mean ET (cm)	Pre-Sill Monthly Mean ET Variance (cm)	With-Sill Monthly Mean ET Variance (cm)	Comparison of Means P > t	Comparison of Variances P > F
January	Fargo	10.14	10.09	0.05	0.02	0.2769	0.0020
	Folkston	10.31	10.16	0.08	0.03	0.0119	0.0156
	Homerville	10.25	10.14	0.05	0.02	0.0186	0.0636
	Nahunta	10.28	10.13	0.05	0.01	0.0013	0.0017
	Waycross 4NE	10.22	10.15	0.05	0.02	0.1486	0.0062
	WSMO	10.17	10.10	0.06	0.02	0.1372	0.0006
February	Fargo	9.73	9.71	0.02	0.01	0.5832	0.2351
	Folkston	9.87	9.86	0.02	0.02	0.6885	0.5856
	Homerville	9.86	9.78	0.01	0.01	0.0076	0.0452
	Nahunta	9.92	9.80	0.02	0.01	0.0001	<0.0001
	Waycross 4NE	9.83	9.77	0.01	0.003	0.0178	<0.0001
	WSMO	9.75	9.72	0.02	0.01	0.3288	0.0490
March	Fargo	11.90	11.78	0.06	0.03	0.0242	0.0272
	Folkston	12.05	12.08	0.07	0.06	0.5977	0.5632
	Homerville	11.86	11.74	0.05	0.02	0.0152	0.0465
	Nahunta	11.85	11.75	0.05	0.02	0.0456	0.0148
	Waycross 4NE	11.85	11.69	0.06	0.02	0.0016	0.0029
	WSMO	11.96	11.84	0.07	0.03	0.0302	0.0101

Table 2-17--continued.

Month	Station	Pre-Sill Monthly Mean ET (cm)	With-Sill Monthly Mean ET (cm)	Pre-Sill Monthly Mean ET Variance (cm)	With-Sill Monthly Mean ET Variance (cm)	Comparison of Means P > t	Comparison of Variances P > F
April	Fargo	14.54	13.84	0.06	0.50	0.0001	<0.0001
	Folkston	14.26	13.29	0.57	0.09	0.0001	<0.0001
	Homerville	14.27	14.01	0.06	0.29	0.0159	<0.0001
	Nahunta	14.22	13.94	0.07	0.32	0.0128	<0.0001
	Waycross 4NE	14.31	13.99	0.05	0.22	0.0009	0.0001
	WSMO	14.66	13.81	0.06	0.56	0.0001	<0.0001
May	Fargo	14.83	14.88	0.10	0.39	0.6693	0.0003
	Folkston	15.24	15.43	0.15	0.08	0.0310	0.0708
	Homerville	14.64	14.45	0.17	0.14	0.0635	0.6179
	Nahunta	14.53	14.53	0.08	0.18	0.9603	0.0165
	Waycross 4NE	14.58	14.46	0.08	0.30	0.2783	0.0009
	WSMO	14.96	15.04	0.10	0.31	0.4790	0.0029
June	Fargo	16.65	16.05	0.10	0.24	0.0001	0.0274
	Folkston	16.62	16.25	0.23	0.13	0.0009	0.1097
	Homerville	16.20	15.94	0.13	0.12	0.0044	0.7140
	Nahunta	16.05	15.70	0.24	0.27	0.0088	0.8010
	Waycross 4NE	16.27	15.77	0.09	0.23	0.0001	0.0109
	WSMO	16.81	16.20	0.11	0.26	0.0001	0.0212

Table 2-17--continued.

Month	Station	Pre-Sill Monthly Mean ET (cm)	With-Sill Monthly Mean ET (cm)	Pre-Sill Monthly Mean ET Variance (cm)	With-Sill Monthly Mean ET Variance (cm)	Comparison of Means P > t	Comparison of Variances P > F
July	Fargo	16.06	16.29	0.06	0.44	0.0724	<0.0001
	Folkston	16.64	17.13	0.17	0.09	<0.0001	0.0787
	Homerville	15.75	15.71	0.12	0.33	0.7044	0.0073
	Nahunta	15.65	15.75	0.06	0.43	0.4484	<0.0001
	Waycross 4NE	15.73	15.74	0.05	0.54	0.9012	<0.0001
	WSMO	16.22	16.62	0.06	0.58	0.0054	<0.0001
August	Fargo	15.84	15.80	0.06	0.12	0.6085	0.0931
	Folkston	16.09	16.18	0.09	0.05	0.1609	0.1779
	Homerville	15.52	15.24	0.08	0.10	0.0004	0.4212
	Nahunta	15.44	15.27	0.06	0.08	0.0149	0.4351
	Waycross 4NE	15.52	15.37	0.06	0.17	0.0722	0.0031
	WSMO	15.99	15.98	0.07	0.12	0.8454	0.1129
September	Fargo	13.40	13.35	0.13	0.29	0.6266	0.0354
	Folkston	13.76	14.08	0.16	0.07	0.0005	0.0141
	Homerville	13.22	13.15	0.12	0.14	0.4710	0.5906
	Nahunta	13.19	13.01	0.11	0.13	0.0448	0.7544
	Waycross 4NE	13.25	13.06	0.12	0.22	0.0694	0.0803
	WSMO	13.50	13.51	0.14	0.31	0.9232	0.0294

Table 2-17--continued.

Month	Station	Pre-Sill Monthly Mean ET (cm)	With-Sill Monthly Mean ET (cm)	Pre-Sill Monthly Mean ET Variance (cm)	With-Sill Monthly Mean ET Variance (cm)	Comparison of Means P > t	Comparison of Variances P > F
October	Fargo	13.05	12.50	0.07	0.21	0.0001	0.0052
	Folkston	12.85	12.23	0.46	0.09	0.0001	<0.0001
	Homerville	12.91	12.54	0.07	0.13	<0.0001	0.1404
	Nahunta	12.91	12.58	0.06	0.09	<0.0001	0.2815
	Waycross 4NE	12.93	12.60	0.06	0.12	0.0001	0.1043
	WSMO	13.14	12.51	0.08	0.24	0.0001	0.0032
November	Fargo	10.20	10.16	0.05	0.03	0.4871	0.2099
	Folkston	10.35	10.40	0.05	0.06	0.3214	0.3810
	Homerville	10.29	10.22	0.04	0.04	0.2044	0.9741
	Nahunta	10.32	10.28	0.04	0.03	0.2911	0.4155
	Waycross 4NE	10.27	10.24	0.04	0.09	0.7197	0.0752
	WSMO	10.23	10.23	0.05	0.06	0.9923	0.9202
December	Fargo	10.83	10.34	0.08	0.20	0.0001	0.0114
	Folkston	10.59	9.94	0.37	0.02	0.0001	<0.0001
	Homerville	10.84	10.56	0.08	0.10	0.0004	0.5357
	Nahunta	10.87	10.54	0.07	0.14	0.0002	0.0772
	Waycross 4NE	10.86	10.56	0.07	0.15	0.0004	0.0308
	WSMO	10.88	10.30	0.08	0.22	0.0001	0.0076

Table 2-18. Comparison of SCFSP and SCRA water surface elevations above mean sea level (AMSL) before and after construction of the Suwannee River sill, 1941-1995.

Interval	Station	Pre-Sill Monthly Mean Water Surface Elevation (m AMSL)	With-Sill Monthly Mean Water Surface Elevation (m AMSL)	Pre-Sill Monthly Mean Water Surface Elevation Variance (m)	Pre-Sill Monthly Mean Water Surface Elevation Variance (m)	Comparison of Means P > t	Comparison of Variances P > F
Overall	SCFSP	34.79	35.00	0.08	0.06	0.0001	0.0001
	SCRA	36.48	36.56	0.07	0.04	0.0001	<0.0001
Growing Season[a]	SCFSP	34.80	35.00	0.08	0.06	<0.0001	0.1054
	SCRA	36.48	36.56	0.06	0.04	0.0001	0.0007
Non-growing Season	SCFSP	34.79	34.99	0.10	0.06	0.0001	<0.0001
	SCRA	36.48	36.54	0.07	0.04	0.0146	<0.0001
January	SCFSP	34.79	35.03	0.11	0.04	0.0002	0.0001
	SCRA	36.48	36.56	0.07	0.03	0.0850	0.0022
February	SCFSP	34.82	35.15	0.05	0.04	<0.0001	0.5567
	SCRA	36.49	36.63	0.06	0.03	0.0014	0.0067
March	SCFSP	34.87	35.19	0.07	0.04	<0.0001	0.1070
	SCRA	36.52	36.66	0.06	0.02	0.0015	0.0012
April	SCFSP	34.85	35.12	0.04	0.06	<0.0001	0.1588
	SCRA	36.51	36.63	0.05	0.03	0.0026	0.1267
May	SCFSP	34.74	34.96	0.03	0.03	<0.0001	0.8156
	SCRA	36.44	36.53	0.04	0.03	0.0093	0.1260

Table 2-18--continued.

Interval	Station	Pre-Sill Monthly Mean Water Surface Elevation (m AMSL)	With-Sill Monthly Mean Water Surface Elevation (m AMSL)	Pre-Sill Monthly Mean Water Surface Elevation Variance (m)	Pre-Sill Monthly Mean Water Surface Elevation Variance (m)	Comparison of Means $P > t$	Comparison of Variances $P > F$
June	SCFSP	34.67	34.91	0.05	0.05	<0.0001	0.7006
	SCRA	36.37	36.49	0.05	0.04	0.0056	0.2801
July	SCFSP	34.74	34.94	0.06	0.05	<0.0001	0.5153
	SCRA	36.44	36.52	0.04	0.04	0.0404	0.9555
August	SCFSP	34.81	34.99	0.10	0.07	0.0011	0.1812
	SCRA	36.49	36.57	0.07	0.05	0.0600	0.2629
September	SCFSP	34.85	34.99	0.10	0.08	0.0178	0.3524
	SCRA	36.53	36.58	0.08	0.06	0.3985	0.3305
October	SCFSP	34.85	34.92	0.13	0.07	0.3088	0.0139
	SCRA	36.54	36.53	0.09	0.06	0.7839	0.1373
November	SCFSP	34.78	34.87	0.14	0.05	0.1819	0.0001
	SCRA	36.49	36.48	0.09	0.05	0.7264	0.0332
December	SCFSP	34.76	34.92	0.12	0.06	0.0125	0.0041
	SCRA	36.46	36.49	0.09	0.04	0.5277	0.0107

[a] Growing season includes March-October; non-growing season includes January-February and November-December.

Table 2-19. Differences in mean monthly precipitation among decades at SCFSP and SCRA, and 95% confidence intervals. No differences were significant at $\alpha \leq 0.05$. Data were log-normalized before comparisons were made.

Station	Interval	Parameter	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1993
SCFSP	1940-1949	Difference Between Means (cm)	---	0.94	1.02	1.02	-1.04	-1.10
		95% CI	---	0.81-1.10	0.87-1.19	0.87-1.19	0.83-1.12	0.76-1.09
	1950-1959	Difference Between Means (cm)		---	1.08	1.08	1.02	-1.04
		95% CI		---	0.92-1.27	0.92-1.27	0.88-1.19	0.76-1.09
	1960-1969	Difference Between Means (cm)			---	-1.00	-1.06	-1.12
		95% CI			----	0.85-1.18	0.81-1.11	0.74-1.07
	1970-1979	Difference Between Means (cm)				---	-1.06	-1.12
		95% CI				---	0.81-1.11	0.74-1.08

Table 2-19--continued.

Station	Interval	Parameter	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1993
	1980-1989	Difference Between Means (cm)					---	-1.06
		95% CI					---	0.78-1.13
SCRA	1940-1949	Difference Between Means (cm)	---	0.95	1.02	1.02	0.96	0.89
		95% CI	---	0.82-1.09	0.88-1.18	0.88-1.18	0.84-1.11	0.75-1.05
	1950-1959	Difference Between Means (cm)		---	1.08	1.08	1.02	0.94
		95% CI		---	0.93-1.25	0.93-1.25	0.89-1.17	0.79-1.11
	1960-1969	Difference Between Means (cm)			---	1.00	0.95	1.15
		95% CI			---	0.86-1.17	0.82-1.10	0.73-1.04

Table 2-19--continued.

Station	Interval	Parameter	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1993
	1970-1979	Difference Between Means (cm)				---	0.95	0.87
		95% CI				---	0.82-1.10	0.73-1.04
	1980-1989	Difference Between Means (cm)					---	0.92
		95% CI					---	0.77-1.09

and lowest totals occurred during the 1930s (possibly due to continent-wide drought conditions of the "dust bowl" era) and 1980s. Biweekly precipitation totals were intermediate during the 1940s, 1950s, and 1990s. At SCFSP water levels were highest during the 1960s and 1970s, lowest during the 1940s, 1950s, and 1980s, and intermediate during the 1990s (Table 2-20). At SCRA water levels were highest during the 1970s and 1990s, lowest during the 1950s and 1980s, and intermediate during the 1940s and 1960s. During the with-sill period, high and medium water level periods have corresponded to periods of high precipitation, whereas lower water levels occurred prior to the sill's construction when average precipitation volumes were also lower. The sill's affect appears to be mainly during high water and high precipitation periods, and when precipitation decreases, water levels in the sill area (represented by SCFSP) and throughout the swamp (represented by SCRA) also decrease (Figure 2-17). This indicates that the intended purpose of the Suwannee River Sill "to prevent drainage of the Okefenokee Swamp during periods of drought" may not be achievable with the existing sill configuration, and correlation of swamp water level and precipitation volume.

Topography Surface

The swamp topographic surface was interpolated from elevation data collected by 4 methods: Global Positioning System (GPS) survey (106 points), laser transit survey (48 points), "flatpool" survey (498 points), and USGS 7.5" 1:25,000 topographic quadrangles (362 points). Elevations above mean sea level (AMSL) representing the peat and

Table 2-20. Differences in mean biweekly water surface elevation among decades at SCFSP and SCRA, and 95% confidence intervals. Differences marked with * are significant at $\alpha \leq 0.05$.

Station	Interval	Parameter	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1993
SCFSP	1940-1949	Difference Between Means (cm)	---	-0.20*	0.09*	0.17*	0.05	0.07
		95% CI	---	-0.27 - -0.13	0.03 - 0.16	0.11 - 0.24	-0.02 - 0.12	-0.01 - 0.345
	1950-1959	Difference Between Means (cm)		---	0.30*	0.37*	0.25*	0.27*
		95% CI		---	0.23 - 0.36	0.31 - 0.44	0.19 - 0.32	0.19 - 0.35
	1960-1969	Difference Between Means (cm)			---	0.08*	-0.04	-0.03
		95% CI			----	0.01 - 0.15	-0.11 - 0.02	-0.10 - 0.05
	1970-1979	Difference Between Means (cm)				---	-0.12*	-0.11*
		95% CI				---	-0.19 - -0.06	-0.18 - -.023
	1980-1989	Difference Between Means (cm)					---	0.02
		95% CI					---	-0.06 - 0.10

Table 2-20--continued.

Station	Interval	Parameter	1940-1949	1950-1959	1960-1969	1970-1979	1980-1989	1990-1993
SCRA	1940-1949	Difference Between Means (cm)	---	-0.13*	0.01	0.05	-0.04	0.02
		95% CI	---	-0.19 - -0.07	-0.05 - 0.07	-0.01 - 0.11	-0.09 - 0.02	-0.05 - 0.09
	1950-1959	Difference Between Means (cm)		---	0.14*	0.18*	0.09*	0.15*
		95% CI		---	0.08 - 0.20	0.02 - 0.23	0.04 - 0.15	0.08 - 0.22
	1960-1969	Difference Between Means (cm)			---	0.04	-0.05	0.01
		95% CI			---	-0.02 - 0.09	-0.10 - 0.01	-0.06 - 0.08
	1970-1979	Difference Between Means (cm)				---	-0.08*	-0.03
		95% CI				---	-0.14 - -0.02	-0.10 - 0.04
	1980-1989	Difference Between Means (cm)					---	0.05
		95% CI					---	-0.01 - 0.12

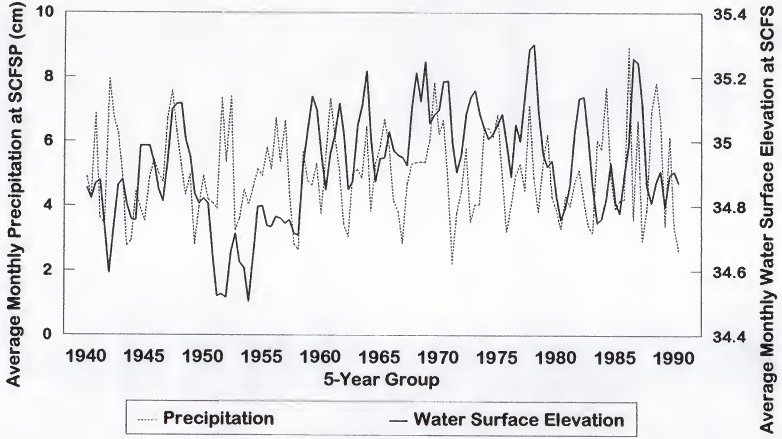


Figure 2-17. Average monthly precipitation and water surface elevation reported by 5-year intervals at SCFSP, during 1941-1994.

underlying sand surfaces, and the thickness of the peat on the sand surface, were calculated and included in the data sets, which were interpolated to create data grids. The sand and peat surface grids were combined to create a topographic surface used to direct water movement in the swamp hydrology model, and the peat thickness surface was used in comparisons of vegetation community types, fire history, and peat characterizations.

Collection of Point Elevation Data

During October 1991-March 1993 permanent survey benchmarks were established at 86 locations within the Okefenokee National Wildlife Refuge and its perimeter. At each site a 3.2 cm diameter galvanized pipe was driven through the water, peat, and/or sand surfaces; one end of the pipe was buried at least 1 m into the sand, and the other extended 1-2 m above the water surface. Each pipe was topped with a galvanized cap onto which a 2.5 cm stainless steel bolt and nut had been welded. The top surface of the welded nut served as the reference point for measuring water depth, peat surface elevation, and depth to the sand basement below the peat surface; the bolt was the attachment site for a GPS antenna. A rebar probe was driven through the peat to the sand surface to estimate peat thickness, and a meter stick and tape measure were used to measure water depth and distance from the water surface to the reference point. The elevation relative to mean sea level of the top surface of the reference nut was estimated in GPS surveys conducted with assistance from U.S. Fish and Wildlife Service professional surveyors during October 1991-March 1993. Differences between the

reference point elevation and the distance to the peat and sand surfaces provided estimates of the peat and sand surface elevations (Table 2-21). Control data were collected at 20 additional benchmarks in the swamp perimeter (Table 2-21). Absolute elevation for any surveyed benchmark was within 10 cm of first order mean sea level datum (NGVD 29). Elevation of any point relative to the nearest control point referenced in the survey was 6 cm. Between any 2 adjacent points within the same survey network, the error was ≤ 3 cm. Several of the surveyed benchmarks also served as support poles for the water level recorder platforms; these benchmarks were the elevations to which the recorders were referenced. Stevens chart recorders, water depth staffs, and digital recorders not installed at permanent benchmarks were referenced to a benchmark located within 500 m of the recorder station using a laser transit and level.

Additional points were surveyed among the GPS benchmarks during November 1991-April 1994 to improve the spatial resolution of the topographic database. A laser transit and level referenced to nearby GPS benchmarks were used to survey points in Chesser, Grand, and Durdin Prairies, and the sill dike. A "flatpool" survey was also conducted during high water periods to improve data resolution; the water surface was determined flat by reference to nearby benchmarks. At each "flatpool" point, percent cover of vegetation types in a 30x30 m plot was estimated independently by 2 observers and averaged. Water depth measurements were made at 3 locations within each vegetation type, and the average depths were weighted by the averaged vegetation percent coverages to estimate a site water depth, which was referenced to the nearest benchmark to estimate peat surface elevation. Three depth measurements to the peat and

Table 2-21. Elevations and locations of benchmarks established in the Okefenokee Swamp National Wildlife Refuge and perimeter, and peat and sand surface elevations above mean sea level (AMSL) at each site.

Region of Benchmark Location	Benchmark Number	Benchmark Top (Nut) Elevation (m AMSL)	UTM X Location Coordinate	UTM Y Location Coordinate	Peat Surface[a] Elevation (m AMSL)	Sand Surface Elevation (m AMSL)
SCRA	35	37.65	390885	3401095		37.35
North Chesser Prairie	1	38.13	387428	3400187	36.24	34.46
Chesser Prairie Recorder	2	37.91	386384	3398182	35.68	33.39
Seagrove Lake	17	37.80	387656	3398068	36.50	34.07
South Chesser Prairie	18	38.20	386373	3396592	36.27	34.07
Grand Prairie	3	37.41	385046	3396068	36.42	34.44
Grand Prairie	36	38.25	384921	3394716	36.38	33.20
Grand Prairie	4	37.57	383293	3394205	36.55	32.83
Grand Prairie	5	37.89	383605	3393529	36.55	32.75
Grand Prairie	6	37.90	382103	3394178	36.55	32.66
Grand Prairie	37	38.24	382589	3393537	36.44	33.44
Grand Prairie	38	37.84	380402	3392682	36.53	33.95
Mizell Prairie	15	37.71	386430	3402736	36.31	34.74
Mizell Prairie	16	37.71	388506	3404200	36.46	34.14

Table 2-21--continued.

Region of Benchmark Location	Benchmark Number	Benchmark Top (Nut) Elevation (m AMSL)	UTM X Location Coordinate	UTM Y Location Coordinate	Peat Surface[a] Elevation (m AMSL)	Sand Surface Elevation (m AMSL)
South of Christie Prairie	86	38.52	388785	3406965	36.57	34.25
Buck Prairie	39	38.11	384464	3401820	36.39	35.08
Buck Prairie	40	38.06	384920	3400397	36.31	34.14
Coffee Bay	41	37.32	382461	3403711	36.39	35.51
Coffee Bay	42	37.92	382134	3403906	36.45	34.60
West End Suwannee Canal	66	38.15	378022	3410249	35.60	32.90
Chase Prairie	7	37.62	382883	3407863	36.18	33.78
Chase Prairie	8	37.26	380059	3413021	36.21	32.86
Chase Prairie	9	37.55	383563	3409813	36.14	33.72
Chase Prairie	10	37.58	383653	3407930	36.21	33.01
Chase Prairie	11	37.20	382533	3413067	36.22	32.67
Chase Prairie	14	37.40	382035	3410668	36.35	33.51
Territory Prairie	12	37.76	384562	3414475	36.59	34.15
Territory Prairie	13	37.86	386337	3415716	36.66	31.95
Durdin Prairie	31	38.43	389339	3423046	37.58	34.94

Table 2-21--continued.

Region of Benchmark Location	Benchmark Number	Benchmark Top (Nut) Elevation (m AMSL)	UTM X Location Coordinate	UTM Y Location Coordinate	Peat Surface[a] Elevation (m AMSL)	Sand Surface Elevation (m AMSL)
Durdin Prairie	32	38.29	390543	3421296	36.51	34.78
Durdin Prairie	33	38.24	389632	3419011	36.94	35.18
Durdin Prairie Recorder	54	39.11	389384	3416529	36.98	34.54
South of Half Moon Lake	34	38.18	390025	3415550	37.19	34.83
Kingfisher Landing	30	39.26	391382	3425256		38.42
South End of Billy's Lake	52	35.96	368219	3411227	34.22	32.50
Billy's Lake Recorder	67	36.31	371204	3412079	33.60	32.30
North End of Billy's Lake	51	36.59	372056	3412004	34.42	32.89
South End of Minnie's Lake	50	36.20	373243	3414629	34.57	31.36
North End of Minnie's Lake	49	36.39	374185	3415847	34.79	33.24
Floyd's Prairie	44	36.66	375920	3415735	35.33	32.86
Floyd's Prairie Recorder	48	37.39	376722	3415985	35.27	32.77
Floyd's Prairie	46	37.08	378200	3415247	35.71	32.51
Floyd's Prairie	45	37.49	376872	3416930	35.03	32.22
Floyd's Prairie	47	36.76	377382	3418179	35.53	31.93

Table 2-21--continued.

Region of Benchmark Location	Benchmark Number	Benchmark Top (Nut) Elevation (m AMSL)	UTM X Location Coordinate	UTM Y Location Coordinate	Peat Surface[a] Elevation (m AMSL)	Sand Surface Elevation (m AMSL)
Suwannee River Recorder	58	35.17	366684	3409485	33.62	33.00
Sill Area	57	35.37	364780	3408483	34.01	33.82
Sill Area	63	35.85	364507	3407957	34.17	33.82
Craven's Hammock Trail	64	3546	364433	3411925	34.03	33.00
Craven's Hammock Trail	60	35.48	364411	3412823	34.05	33.29
Craven's Hammock Trail	61	35.83	364496	3414644	34.37	33.24
Craven's Hammock Trail	59	35.78	366293	3410732	34.13	32.98
Craven's Hammock Recorder	62	36.63	364593	3417889		35.15
Craven's Hammock Trail	65	35.79	364271	3415136	34.37	33.76
Suwannee River Sill	55	36.57	364905	3409593		35.66
Suwannee River Sill	56	36.66	364456	3411424		35.90
Double Lakes	29	38.48	386096	3429028	37.35	35.71
Pond Lake	28	38.72	386132	3430683	37.36	35.05
Ohio Lake	27	38.56	385031	3432360	37.22	34.78
Maul Hammock	26	38.48	380178	3432181	37.10	34.61

Table 2-21--continued.

Region of Benchmark Location	Benchmark Number	Benchmark Top (Nut) Elevation (m AMSL)	UTM X Location Coordinate	UTM Y Location Coordinate	Peat Surface[a] Elevation (m AMSL)	Sand Surface Elevation (m AMSL)
Sapling Prairie	25	38.53	378807	3433114	36.94	34.40
Sapling Prairie	24	38.46	376750	3431924	36.66	34.23
Sapling Prairie	22	38.13	377599	3431030	36.86	34.40
Sapling Prairie Recorder	53	37.76	377514	3430102	36.61	34.56
Sapling Prairie	21	37.80	377733	3429414	36.64	34.63
Sapling Prairie	23	38.22	379635	3432172	36.48	34.72
Dinner Pond Area	20	37.72	376751	3428010	36.56	34.82
Dinner Pond Area	19	37.89	377222	3427244	36.44	35.77
Sweetwater Creek Recorder	70	36.35	357684	3398307		34.04
Cypress Creek	85	35.86	356041	3391746		33.95
Suwannee Creek	88	38.23	360430	3425750		37.04
Honey Prairie Recorder	69	38.67	370747	3400759	36.11	34.74
Blackjack Prairie	81	38.36	380030	3392863	36.72	35.84
Blackjack Island	71	38.33	377360	3391812		38.28
Billy's Island	72	37.77	372450	3410983		37.72

Table 2-21--continued.

Region of Benchmark Location	Benchmark Number	Benchmark Top (Nut) Elevation (m AMSL)	UTM X Location Coordinate	UTM Y Location Coordinate	Peat Surface[a] Elevation (m AMSL)	Sand Surface Elevation (m AMSL)
Floyd's Island	73	38.55	380794	3415763		38.53
Greasy Branch Island	74	37.94	368224	3427655		37.88
Minnie's Island	75	36.65	370935	3418150		36.59
Bugaboo Island	76	38.18	378706	3403521		38.05
Fiddler's Island	77	36.58	361745	3391227		36.47
Mitchell Island	78	38.41	381136	3388713		38.29
Rowell's Island	79	36.72	355211	3411890		36.60
Honey Island	80	38.18	372613	3404567		38.12
Moonshine Ridge	82	37.53	379185	3383736		36.08
Black Hammock	83	39.66	372825	3436319		38.28
Pine Island	84	37.22	362911	3413138		35.35
Highway 94-185 Junction, Moniac	B144-1001	36.53	383003	3377062		36.43
Ellicott's Mound	ELLMND-1002	34.85	383507	3382414		34.75
Soldier's Camp Road	OKECP3-103	35.83	383053	3384364		35.73
Camp Cornelia Helicopter Pad	OKECP2-102	45.18	391990	3400991		45.18

Table 2-21--continued.

Region of Benchmark Location	Benchmark Number	Benchmark Top (Nut) Elevation (m AMSL)	UTM X Location Coordinate	UTM Y Location Coordinate	Peat Surface[a] Elevation (m AMSL)	Sand Surface Elevation (m AMSL)
Rogers and Buddy Harris Roads	DAVIS-111	45.97	392108	3405698		45.92
Mizell Road TT11	CREWS-110	44.86	392186	3424211		44.76
US1/23 9.5 mi N Folkston	Y141T-1007	35.63	394150	3424166		35.60
Racepond Highway 1/121 Junction	C142T-1008	45.95	392484	3429465		45.92
SE Waycross, RR Marker S107	A317-1009	44.54	382176	3441714		44.44
Cowhouse Island Helicopter Pad 1	OKECP1-101	38.36	381541	3435649		38.26
Cowhouse Island Helicopter Pad	COWHSE-1004	38.43	380338	3435883		38.33
15 mi SE Waycross	FISH-1003	38.21	369112	3431046		38.11
Hopkins Tram and Mill Road	109SKS-114	39.51	363365	3428810		39.41
Roads 28 and 30, NE of Fargo	101SKS-1014	39.50	351769	3423010		39.40
SCFSP Turn-around at Boat House	OKECP5-105	35.63	369869	3411454		35.75
Sapp Prairie Road	OKECP4-104	36.80	365640	3387973		36.75
3.3 mi NE Eddy Fire Tower	J183T-1018	37.64	366618	3382027		37.74
Eddy Fire Tower	K183T-1019	39.54	371172	3379801		39.66
Chesser Island USGS 2	X2T-113	38.52	389126	3398428		38.52

Table 2-21--continued.

Region of Benchmark Location	Benchmark Number	Benchmark Top (Nut) Elevation (m AMSL)	UTM X Location Coordinate	UTM Y Location Coordinate	Peat Surface[a] Elevation (m AMSL)	Sand Surface Elevation (m AMSL)
North Spillway of Suwannee Sill	X9T-1016	35.26	364765	3410127		35.26
South Spillway of Suwannee Sill	OKECP6-106	35.60	364418	3408757		35.64

[a] Benchmark locations without peat are left blank.

sand surface using the rebar probe were also made at the "flatpool" sites to use in peat thickness estimates. Peat elevation estimates were also made at all transect sampling points (see Chapter 6) and averaged to represent peat elevation in the transect area. To complete the point data in inaccessible regions of the swamp, point elevations were taken from 1966 USGS 7.5" 1:25,000 quadrangles after determining that the GPS survey elevation data agreed with the USGS elevation data in the swamp perimeter. These points supplemented GPS survey points on the large interior islands, or were outside the refuge perimeter (Figure 2-18).

Surface Interpolation

A topographic grid was created for the combined peat and sand surfaces (peat, or sand where no peat occurred) using ARCINFO-GRID's kriging procedure on the PEATELEV coverage item. Several algorithms and grid sizes were used, with the circular model and 500x500 m cell size resulting in the best semivariogram (Burroughs 1986). The resultant surface was compared to the original data points to check the interpolation accuracy (Figure 2-19). A correction surface was added to the interpolated surface to adjust for interpolation errors, and the final grid was smoothed with a filter (5x5 cell, or 2500x2500 m, mean window) to eliminate pits and peaks in the estimated surface (Figure 2-20).

The swamp peat thickness was calculated by differencing the sand elevations and peat surface elevations at each surveyed point; 19 additional peat thickness estimates reported by Cohen et al. (1984) were added to supplement the grid. Inaccessibility made collection of peat thickness data in the south-central region of the swamp impossible;

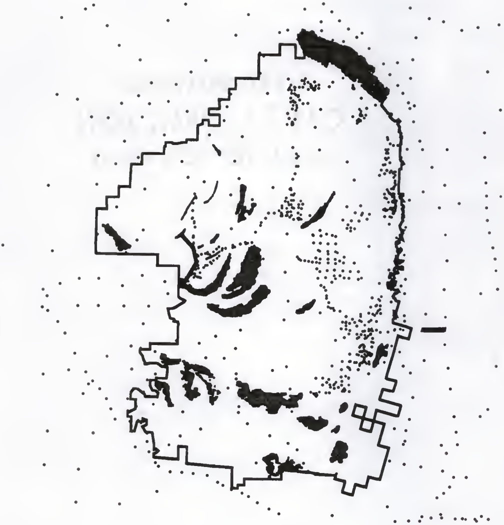


Figure 2-18. Locations surveyed and extracted from USGS 1994 1:24,000 topographic maps for development of the Okefenokee Swamp topographic surface.

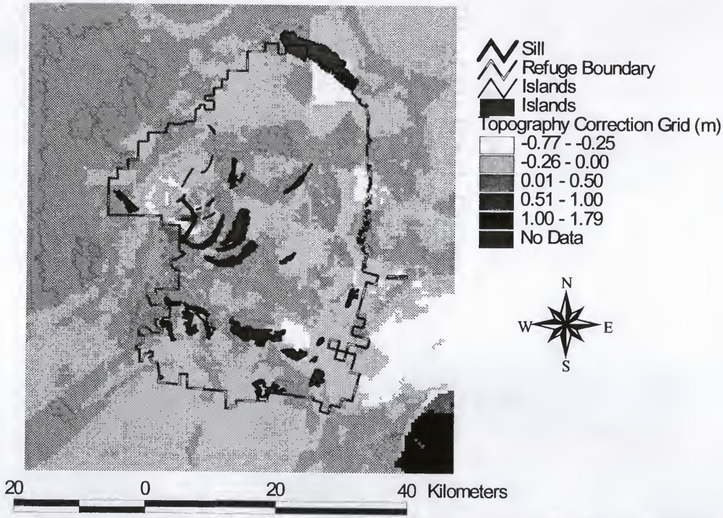


Figure 2-19. Correction surface used to adjust the swamp topography map, generated from the difference between the actual and interpolated surface elevation data.

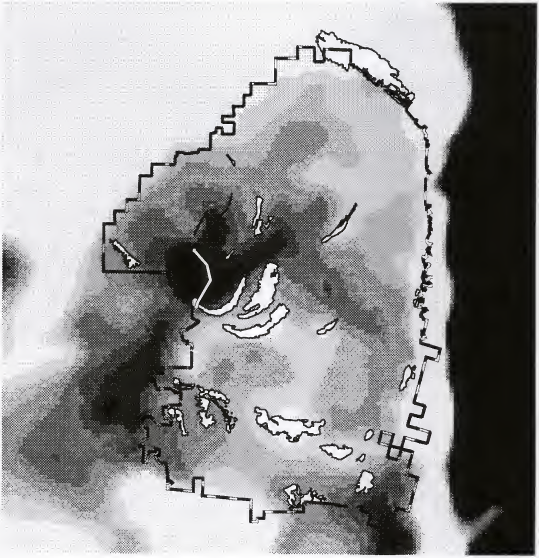


Figure 2-20. Peat and sand surface topography in Okefenokee Swamp. Darker areas are lower in elevation above mean sea level.

therefore, peat thicknesses in this area were estimated from those associated with vegetation types in other regions of the swamp. Five points were randomly selected in each vegetation type (except on large sand-based islands) in the south-central swamp. Peat thicknesses for each vegetation type in the remainder of the swamp were averaged and applied to the randomly selected points in the south-central swamp (Table 2-22). An estimated peat thickness grid was created by kriging this combined dataset with the circular model and 500x500 m cell size (Figure 2-21). A sand surface elevation grid was created by subtracting the estimated peat thickness grid from the original peat surface elevation grid (Figure 2-22).

Topography Surface Description and Trends

Topographic relief in the swamp is minimal. The swamp is a bowl-like depression in the landscape with the trend in ground surface elevations from 38.4 m at Kingfisher Landing in the Northeast to 33.0 m in the area where the Suwannee River exits the swamp in the West to 34.8 m at Ellicott's Mound in the Southeast near the St. Marys River outflow. Basement sand topography also follows this trend. Within the swamp are regional topographic highs on large sand-based islands and lows in large prairies and stream beds, ranging in elevation from 38.4 to 33.6 m AMSL. The prairies also contain local topographic highs on peat-based islands that may raise a meter above the surrounding inundated peat surface (Figure 2-23). This local topographic variation results in gradients of vegetation community distributions within the prairies; the forest matrix between the prairies has less topographic variation and a less diverse vegetation

Table 2-22. Peat thickness values used to estimate peat depth by vegetation type, to supplement the coverage of estimated peat depths where data gaps exist.

Vegetation Type	Number of Cells	Area (ha)	Mean Peat Thickness (m)	Minimum Peat Thickness (m)	Maximum Peat Thickness (m)	Variance in Peat Thickness (m)
Gum-Maple-Bays	23	575	0.99	0.45	2.26	0.32
Water Lily	63	1575	2.87	0.51	3.62	0.32
Gum-Bay-Cypress-Shrub	476	11900	1.56	0.37	3.41	0.62
Mixed Wet Pine	7	175	1.70	1.58	1.90	0.01
Sedges-Ferns-Water Lilies	349	8725	1.90	0.37	3.67	0.70
Briar-Shrub	124	3100	2.61	0.69	3.57	0.46
Open Water	3	75	2.53	2.13	3.32	0.31
Bay-Shrub	868	21700	1.82	0.37	3.63	0.87
Cypress-Gum-Shrub	1217	30425	1.79	0.37	3.58	0.88
Loblolly Bay	418	10450	1.61	0.37	3.20	0.64
Shrub	174	4350	1.67	0.38	3.50	0.75
Dense Pine	50	1250	0.90	0.37	3.24	0.48
Sparse Pine	20	500	0.78	0.37	2.10	0.43
Mixed Upland/Wetland Shrubs	9	225	0.75	0.42	1.24	0.07
Pine-Cypress-Hardwoods	37	925	1.15	0.38	2.96	0.49

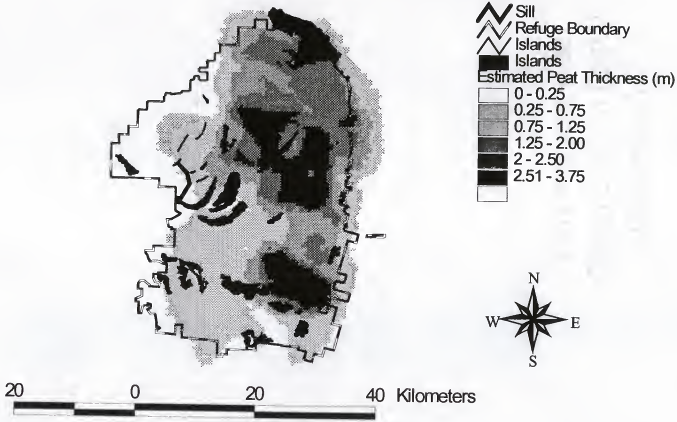


Figure 2-21. Estimated thickness of peat over the basement sands in Okefenokee Swamp.

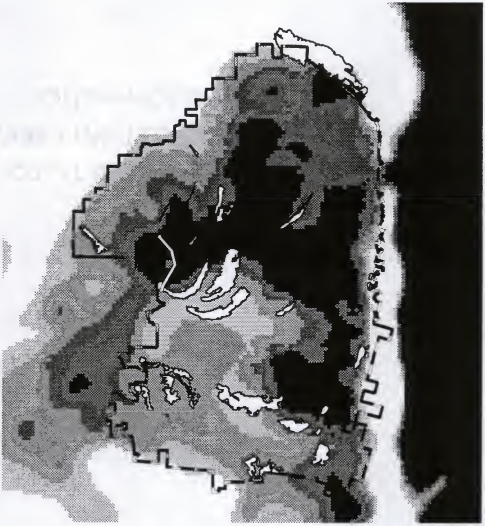


Figure 2-22. Estimated sand surface elevation above mean sea level under the surface peat in Okefenokee Swamp.

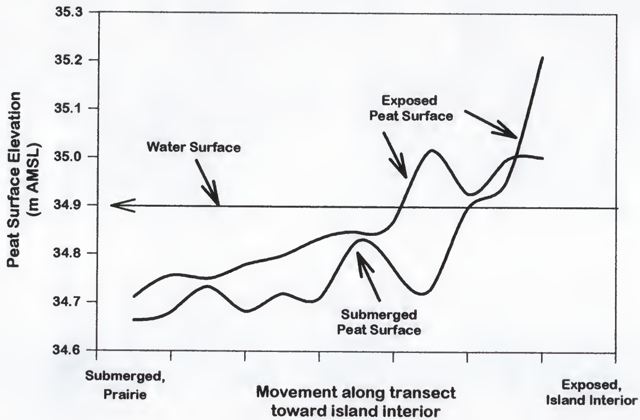


Figure 2-23. Elevation gradients recorded along transects in Okefenokee Swamp prairies.

composition (see Chapters 5 and 6). The regional gradients in topographic elevation direct water movement through the swamp, towards the Southwest and Southeast (see Chapter 3). Peat thickness is greatest in the prairies found primarily in the central and eastern swamp, most likely due to the ponding of water in these topographic lows which decreases decomposition of the accumulated peat. The peat surface is occasionally exposed during periods of extremely low rainfall, which occur every 20-30 years; oxidation during this exposure and removal of peat by widespread fires lower the surface elevation and result in greater inundation when normal precipitation resumes.

Water flows through the swamp along natural and maintained rivers, creeks, and trails (Figure 2-24). The topographic surface in these drainages is terraced, so that the dendritic flow patterns visible on aerial photography and satellite imagery on the swamp represent local topographic highs or berms (Figure 2-25) over which water flows. Upstream from these berms are ponds and lakes (e.g., Dinner Pond, Big Water, Minnie's Lake, Billy's Lake, Cravens Lake) which crest over the berm during high water periods, and are impounded behind the berms when water levels drop. Beyond the berm summit, the elevation drops to the next "impounded" lake or pond in the stream bed. The sill probably acts as one of these berms in the Suwannee River drainage, so that during high water periods, water crests the sill gates and is impounded upstream to and possibly beyond the next highest elevation or berm at the southwest outlet of Billy's Lake. During drier periods when the river is confined to its banks, water is impounded to the northeast of Billy's Lake by this natural berm, beyond the area of impact of the sill berm (see Chapter 3).

Figure 2-24. Creeks, rivers, lakes, and canoe trails where surface water flow occurs in the Okefenokee Swamp.

Figure 2-25. Surface water drainage patterns and underlying topographic gradients in Okefenokee Swamp.

The regional topographic relief creates hydrologic basins and isolates the impounding affects of the sill to the western swamp. The ground surface connectivity of the large, sand-based islands (Floyd's Island to Billy's and Honey Islands and the Pocket; Strange Island to Blackjack and Mitchell's Islands; Moonshine and Soldiers Camp Island area) and intervening and intervening depressions are apparent in the swamp topographic map (Figure 2-20). Water in the central third of the swamp most likely does not drain to the St. Marys River or southwestern creeks even thought the primary gradient is in this direction, because these large islands impede flow. Cohen (1973b) believed that Floyd's, Grand, and Chase Prairie are persistent prairies, probably due to these sub-peat depressions being isolated by ridges (Davis 1987, Smedley 1968). There is some water movement along the Suwannee Canal to the west due to the overall topographic gradient in that direction; however, prior to the canal's construction, this water movement was probably restricted by this natural berm, and most water moving into the Suwannee River and westward probably originated west of the Floyd's-Honey-Billy's Islands and Pocket chain (see Chapter 3). These topographic features determine the spatial hydrologic environment of the swamp, and subsequently influence distributions of vegetation communities (see Chapters 4 and 6).

Satellite Imagery Classification and Accuracy Assessment

Classified satellite imagery provides a geographically referenced record of the vegetation community composition and distribution over a large area at a point in time. Depending on the satellite data scale and quality, imagery can be classified to provide

high resolution information of existing vegetation distributions. Lo and Watson (1994) classified Landsat thematic mapper data in mapping Okefenokee Swamp vegetation and determined that the 30 m data resolution was insufficient for making class distinctions in the patchy environment of the swamp. The spatial complexity of the swamp vegetation requires image data at a finer resolution. SPOT satellite imagery available from panchromatic (PAN; 10 m pixel size) and multispectral (XS; 20 m pixel size) scanners can be merged with transformation of the hue-saturation-intensity bands to provide data at 10 m resolution (Jensen 1986), a more suitable scale for mapping complex wetland vegetation communities. The classified maps can be compared with interpreted historic imagery or photography to assess occurrence and successional vegetation change (Silveira 1995). The classifications reported herein are used to document present vegetation distributions and change (see Chapter 4). The following accuracy assessment provides an index of map reliability and an indication of class confusions to consider in map interpretation and use.

Image Preparation

SPOT PAN and XS imagery were selected for the vegetation map. The most recent scene available providing growing season (March-October) vegetation and minimal (<10%) cloud cover was 11 May 1990. More recent imagery (through 1994) provided incomplete swamp coverage or contained interference from clouds.

ERDAS version 7.5 and IMAGINE (version 8.2, ERDAS, Inc., Atlanta, GA 30329) image processing software were used to prepare and classify the satellite imagery.

The PAN image was rectified to ground control points selected on 1966, USGS 1:24,000 scale topographic maps (ERDAS 1995). The transformation matrix of the control points from the topographic quad sheet to the satellite image was generated using only ground control points with an error between the locations of less than one pixel (10 m). The file coordinates of the XS image were then rectified to the map coordinates of the PAN image, so that both images would be spatially registered to the same coordinate system. Nearest neighbor re-sampling was used to perform the rectification; this method does not corrupt the original band data so that subsequent image classification has not been compromised (Lillesand and Kiefer 1994).

The complexity of the swamp vegetation requires high resolution data. Combination of the 3-band (green, red, and infrared wavelength reflectance) 20 m XS data with the single band (green-red wavelength reflectance) 10 m PAN data creates an enhanced image that uses the color information of the XS data with the spatial resolution of the PAN data. The bands are combined by re-sampling the XS data to 10 m resolution, transforming the XS data in red, green, and blue color space to hue, saturation, and intensity, and then substituting the XS intensity data with the 10 m PAN data (Lillesland and Kiefer 1994). Then the XS data are back-transformed to red, green, and blue color space, with the color intensity enhanced by the PAN data. The resultant merged image has XS 20 m spectral data at PAN 10 m spatial resolution in 10 m pixels (Figure 2-26). This conversion enhances edge features such as islands or ponds while retaining the spectral information, which facilitates identification of wetland vegetation composition.

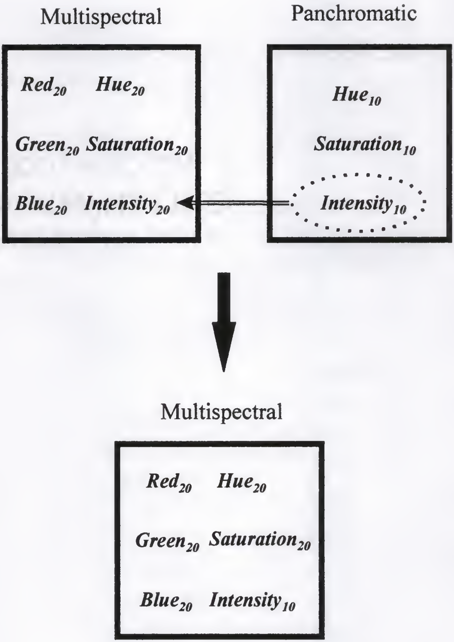


Figure 2-26. Merging 10 m pixel panchromatic and 20 m pixel multispectral imagery to create a multispectral image with 10 m pixel resolution.

A normalized difference vegetation index,

$$[\text{red} - \text{infrared}/(\text{red} + \text{infrared}) * 0.5] * 100$$

was also calculated and added to the merged file as a fourth data band to enhance the interpretation. This band emphasizes vegetation biomass, aiding differentiation from less-densely vegetated areas (Jensen 1986).

Image Classification

Training sites for the image classification were selected from an unsupervised classification of a 10 m resolution 1987 SPOT satellite image merged as described above. Approximately 100 large, single-class areas were selected from the classification for training (seed) and ground control sites. An additional 100 random sites evenly distributed among the four swamp quadrants were also selected as ground control points. Sites were visited during June 1994 by helicopter, and vegetation was identified in the $2500 m^2$ (50x50 m) area below the helicopter, which hovered at an altitude of 50 m. Two observers independently determined the vegetation type and then compared their results to assign a vegetation class. Photographs were taken at each site for later reference. During June 1996, 46 additional sites were visited on the large islands to collect example points of island vegetation to use in classification improvements.

Two PAN and XS satellite scenes were required to cover the entire swamp area. The images were captured as shifts north and south of the same scene, providing considerable overlap in ground coverage. The band data differed slightly among the scenes, requiring that they be matched and then classified. Matching the north and south

scenes was accomplished with histogram matching. This procedure compares the band data histograms and attempts to equalize them in the area to be matched (ERDAS 1995). The edges in the matched area were blended with feathering, and then the images wereclassified. The re-classified edge was then stitched back into the matched image, and the entire image was scanned with a 3x3 pixel majority scan to remove single pixel classes and residual match lines.

An iterative methodology of selecting seed areas at the training sites on the 1990 merged satellite image, examining the signature euclidean distances and photos of each site, and deleting or combining seed sites was used to identify the 36 classes to be used in the initial image classification. A supervised classification of the image with this signature set using the MINDIST algorithm, used due to non-normality in the image band data (ERDAS 1995), resulted in a classification with some class confusions. The classification was repeated by removing some signatures from the set, masking the image to include only specific areas, re-classifying the image portions, and stitching them back into the image. Class distinction was improved by combining signatures and eliminating classes. The band data differed slightly among the scenes, requiring that they be classified with two separate signature sets and then combined along the scene match line. To eliminate the match line, pixels in 4 classes (loblolly bay, gum-bay-cypress-shrub, gum-maple-bay, mature cypress-shrub) were masked from the match area and re-classified with a modified signature set using only band 1-3. The re-classified region was then stitched back into the composite map. The entire classified map was scanned with a 3X3 pixel majority scan (ERDAS 1991) to remove single pixel classes and residual

match lines between the scenes. The classes in the final 22- class map were consolidated to produce the 17-, 13-, and 11-class maps (Table 2-23). The 17-class map was also modified to include improvements to the upland island classification. The large, sand-based islands were removed from the 17-class map, and replaced with a revised classification of the subset area including 4 additional classes representing upland communities (dense pine, sparse pine, mixed upland-wetland shrub, and pine-cypress hardwoods). The resultant composite map of 21 swamp and upland island classes was used in all vegetation change and hydroperiod association analyses (Chapters 4, 5, and 9).

Image Classification Accuracy Assessment

Ground-truthing data collected at 198 sites within the swamp wetland matrix and 46 upland island sites were used to assess the accuracy of the classified maps (Table 2-24). Each site was located on the classified map and the area around it searched for the class of interest. Class occurrence was recorded within radii of 3-5, 10, and >10 pixels (corresponding to 30-50, 100, and >100 m) of the point location. These distances reflected the accuracy of the GPS point locations; differentially correcting the locations resulted in average location adjustments of 25-35 m. It was assumed that if the class occurred within these distances on the classified map then the site classification was correct. Accuracy assessment results are reported for each of these distance groups for the 11-, 13-, 17-, and 22-class maps in Tables 2-25 through 2-28.

Table 2-23. Composition and area of classes in the Okefenokee Swamp satellite image classification.

Vegetation Class, Number	Class Description	Area (ha) of Classes in 22-Class Map	Area (ha) of Classes in 17-Class Map	Area (ha) of Classes in 13-Class Map	Area (ha) of Classes in 11-Class Map	Area (ha) of Classes in Swamp and Islands Map
Bare Ground-Urban (10)	Roads, buildings, parking lots, clearings, bare ground	307	307	307	307	307
Agriculture-Lawn (11)	Planted crops, herbaceous fields, grassy road right-of-ways	7	7	7	7	7
Clearcut-Sparse Pine (12)	Clearcut with/without recent replanting	18	18	18	18	18
100% Upland Pine (1)	Pines dominate overstory, mixed understory of oaks and/or saw-palmetto	118	1728	1728	8078 (all pine classes)	172
Pine-Palmetto (4)	Pine overstory with scattered, dense saw-palmetto understory	1611				
Wetland Pine (21)	Pine dominant overstory (50-100%) with blackgum, loblolly bay, sweet bay, and/or pond cypress subdominant (<30%); may have understory of ferns and shrubs	1221	6350	6350		4422
Pine-Woodwardia (15)	100% pines over ferns, sparse saw-palmetto	3982				
Pine-Gum-Bay (7)	>30% pines; ≤25% blackgum, loblolly bay, shrub	1147				
Mature Cypress-Shrub (18)	25-75% mature cypress overstory with shrub understory (25-50%)	32002	42352	42418	42418	40023
Scrub Cypress-Shrub (19)	≥75% small cypress; ≤25% pines, bay, shrub, prairie	10350				

Table 2-23--continued.

Vegetation Class, Number	Class Description	Area (ha) of Classes in 22-Class Map	Area (ha) of Classes in 17-Class Map	Area (ha) of Classes in 13-Class Map	Area (ha) of Classes in 11-Class Map	Area (ha) of Classes in Swamp and Islands Map
Ogeechee-Cypress (2)	≥50% ogeechee lime with ≤50% cypress overstory	66	66			66
Gum-Maple-Bays (3)	≥75% blackgum with ≤25% loblolly bay, sweet bay, pines, red maple	4318	4318	25904	25904	4254
Gum-Bay-Cypress-Shrub (6)	≥30% blackgum overstory mixed with ≤25% loblolly bay, sweet bay, cypress, and/or shrubs	21586	21586			20949
Mature Loblolly Bay (16)	≥80% loblolly bay mixed with ≤25% pines, cypress, blackgum, sweet bay, mixed shrub understory (≤10%)	19495	19495	53029	53029	19357
Mature Bay-Shrub (17)	≥75% mature loblolly bay overstory with ≤25% shrub understory	32332	33535			30250
Young Bay-Shrub (16)	≥80% young loblolly bay; ≤25% shrub	1202				
Smilax-Shrub (9)	≥75% briar species over shrubs; ≤10% herbaceous and/or aquatic prairie may be present	5035	5035	17468	17468	4500
Shrub (22)	≥50% shrub species, may have scattered scrub species; ≤50% briars; ≤10% herbaceous and/or aquatic prairie may be present	12432	12432			11295
Carex-Nymphaea (8)	Mixture of Walter's sedge, water lily, and fern	11651	11651	11651	13151	10962

Table 2-23--continued.

Vegetation Class, Number	Class Description	Area (ha) of Classes in 22-Class Map	Area (ha) of Classes in 17-Class Map	Area (ha) of Classes in 13-Class Map	Area (ha) of Classes in 11-Class Map	Area (ha) of Classes in Swamp and Islands Map
Nuphar-Nymphaea (5)	≥50% water lily and/or spatterdock with bladderwort	1500	1500	1500		1500
Lacnanthes-Andropogon-Panicum (13)	Mixture of redroot, broomsedge, and maidencane	105	105	105	105	105
Open Water (14)	open water in lakes, canals, rivers	78	78	78	78	78
Pine-Cypress-Hardwoods (22)	Mixture of wet pine, cypress, and bay-maple-blackgum occurring primarily along island fringe					3167
Dense Pine (23)	Upland areas of dense slash or longleaf pine, with saw-palmetto, oaks, and gallberry understory					5207
Sparse Pine (24)	Upland areas of sparse slash or longleaf pine, with saw-palmetto, oaks, and gallberry understory					3380
Mixed Upland/Wetland Shrubs (25)	Mixture of upland and wetland shrubs found on upland islands					536

Table 2-24. Vegetation species found in ground-truthed sites used in the satellite image classification.

Common Name	Scientific Name
Saw-Palmetto	*Serenoa repens*
Virginia Willow	*Itea virginica*
Blueberry	*Vaccineum* spp.
Oak	*Quercus* spp.
Longleaf Pine	*Pinus palustris*
Pond Pine	*Pinus serotina*
Slash Pine	*Pinus elliottii*
Loblolly Bay	*Gordonia lasianthus*
Sweet Bay	*Magnolia virginiana*
Blackgum	*Nyssa sylvatica* v. *biflora*
Pond Cypress	*Taxodium ascendens*
Red Maple	*Acer rubrum*
Titi	*Cyrilla racemiflora*
Fetterbush	*Leucothoe racemosa*
Hurrahbush	*Lyonia lucida*
Fragrant Water Lily	*Nymphaea odorata*
Spatterdock	*Nuphar luteum*
Bladderwort	*Utricularia* spp.
Dahoon Holly	*Ilex cassine*
Chain Fern	*Woodwardia virginiana*
Ogeechee Lime	*Nyssa ogeechee*
Walter's Greenbriar	*Smilax walteriana*
Bamboo Greenbriar	*Smilax laurifolia*
Walter's Sedge	*Carex walteri*

Table 2-24--continued.

Common Name	Scientific Name
Redroot	*Lacnanthes caroliniana*
Broomsedge	*Andropogon virginicus*
Maidencane	*Panicum hemitomon*
Gallberry	*Ilex glabra*

Table 2-25. Error matrix for the 11-class satellite image classification, within 10 pixels (100 m) of ground truth sample point location. Rows are reference data; columns are classification data. Cell values are number of sample points.

Vegetation Class	Gums-Maples-Bays-Cypress-Shrub	Upland and Wetland Pines	Water Lilies	Briar-Shrub	Agriculture-Lawn	Bare Ground-Urban	Clearcut-Sparse Pine	Aquatic Grasses	Open Water	Cypress-Shrub	Loblolly Bay-Shrub	Row Total	User's Accuracy
Gums-Maples-Bays-Cypress-Shrub	19	1		4						2	3	29	66
Upland and Wetland Pines		43										43	100
Water Lilies		1	13									14	93
Briar-Shrub		4		22								26	85
Agriculture-Lawn					1							1	100
Bare Ground-Urban						1						1	100
Clearcut-Sparse Pine							2					2	100
Aquatic Grasses								2				2	100
Open Water									1			1	100
Cypress-Shrub		3		2					1	40		46	87
Loblolly Bay-Shrub		5		2							26	33	79
Column Total	19	57	13	30	1	1	2	2	2	42	29		

Table 2-25--continued.

Vegetation Class	Gums-Maples-Bays-Cypress-Shrub	Upland and Wetland Pines	Water Lilies	Briar-Shrub	Agriculture-Lawn	Bare Ground-Urban	Clearcut-Sparse Pine	Aquatic Grasses	Open Water	Cypress-Shrub	Loblolly Bay-Shrub	Row Total	User's Accuracy
Producer's Accuracy	100	75	100	73	100	100	100	100	50	95	90		

Overall Accuracy = 86%, K = 0.83, V(K) = 0.0006

Table 2-26. Error matrix for the 13-class satellite image classification, within 10 pixels (100 m) of ground truth sample point location. Rows are reference data; columns are classification data. Cell values are number of sample points.

Vegetation Class	Gum-Maple-Bay-Cypress-Shrub	Upland Pine	Water Lilies	Wetland Pine	Sedges-Ferns-Water Lilies	Briar-Shrub	Agriculture-Lawn	Bare Ground-Urban	Clearcut-Sparse Pine	Aquatic Grasses	Open Water	Cypress-Shrub	Loblolly Bay-Shrub	Row Total	User's Accuracy
Gum-Maple-Bay-Cypress-Shrub	19			1		4						2	3	29	66
Upland Pine		19		1										20	95
Water Lilies			2		2									4	50
Wetland Pine		5		18										23	78
Sedges-Ferns-Water Lilies			1	1	8									10	80
Briar-Shrub		1		3		22								26	85
Agriculture-Lawn							1							1	100
Bare Ground-Urban								1						1	
Clearcut-Sparse Pine									2					2	100
Aquatic Grasses										2				2	100
Open Water											1			1	100
Cypress-Shrub				3		2					1	40		46	100

Table 2-26--continued.

Vegetation Class	Gum-Maple-Bay-Cypress-Shrub	Upland Pine	Water Lilies	Wetland Pine	Sedges-Ferns-Water Lilies	Briar-Shrub	Agriculture-Lawn	Bare Ground-Urban	Clearcut-Sparse Pine	Aquatic Grasses	Open Water	Cypress-Shrub	Loblolly Bay-Shrub	Row Total	User's Accuracy
Loblolly Bay-Shrub				5		2								33	86
Column Total	19	25	3	32	10	30	1	1	2	2	2	42	29		
Producer's Accuracy	100	76	67	56	80	73	100	100	100	100	50	95	90		

Overall Accuracy = 81%, K = 0.78, V(K) = 0.0008

Table 2-27. Error matrix for the 17-class satellite image classification, within 10 pixels (100 m) of ground truth sample point location. Vegetation class number refers to Table 2-23. Rows are reference data; columns are classification data. Cell values are number of sample points.

Vegetation Class Number	1, 4	2	3	5	6	7, 15, 21	8	9	10	11	12	13	14	16, 17	18, 19	20	22	Row Total	User's Accuracy
1, 4	19																	20	95
2		1																1	100
3			2															2	100
5				2			2											4	50
6			5		12	1								2	2	1	4	27	44
7, 15, 21	5					18												23	78
8				1		1	8											10	80
9	1					1		4									1	7	57
10									1									1	100
11										1								1	100
12											2							2	100
13												2						2	100
14													1					1	100
16, 17						5								12		2	1	20	60
18, 19						3		1					1		39		1	45	87
20														2		10	1	13	77
22						2		2									15	19	79

Table 2-27--continued.

Vegetation Class Number	1, 4	2	3	5	6	7, 15, 21	8	9	10	11	12	13	14	16, 17	18, 19	20	22	Row Total	User's Accuracy
Column Total	25	1	7	3	12	32	10	7	1	1	2	2	2	16	41	13	23		
Producer's Accuracy	76	100	29	67	100	56	80	57	100	100	100	100	50	75	95	77	65		

Overall Accuracy = 75%, K = 0.72, V(K) = 0.0153

Table 2-28. Error matrix for the 22-class satellite image classification, within 10 pixels (100m) of ground truth sample point location. Vegetation class number refers to Table 2-23. Rows are reference data; columns are classification data. Cell values are number of sample points.

Vegetation Class Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Row Total	User's Accuracy
1	12																						12	100
2		1																					1	100
3			2																				2	100
4	1			6											1								8	75
5					2			2															4	50
6			5			12	1									2		1	1	1		4	27	44
7				2			7								2						1		12	58
8					1		1	8															10	80
9				1					4												1	1	7	57
10										1													1	100
11											1												1	100
12												2											2	100
13													2										2	100
14														1									1	100
15	1			1			5																7	0
16																2							2	100
17							3									1	9			2	2	1	18	50
18							2		1					1				22	2			1	29	76
19															1			4	11				16	69
20																1	1			10		1	13	77

Table 2-28--continued.

Vegetation Class Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Row Total	User's Accuracy
21	1																				3		4	75
22							1		2						1							15	19	79
Column Total	15	1	7	10	3	12	20	10	7	1	1	2	2	2	5	6	10	27	14	13	7	23		
Producer's Accuracy	80	100	29	60	67	100	35	80	57	100	100	100	100	50	0	33	90	81	79	77	43	65		

Overall Accuracy = 67%, K = 0.65, V(K) = 0.001

Overall map accuracy was computed by dividing the number of correctly classified sample sites by the total number of sites. User's and producer's accuracies were calculated for each matrix. User's accuracy (errors of commission; # correctly classified sites in a category / total # sites placed in that category) indicates the likelihood that a classified pixel actually is that class on the ground. Producer's accuracy (errors of omission; # correctly classified sites in a category / # reference sites in that category) indicates whether reference sites were correctly classified (Lillesand and Kiefer 1994).

Reliability of the classification can be assessed with the Kappa coefficient of agreement (K). The coefficient measures whether agreement between the actual points and the classification is true or due to chance (Lillesand and Kiefer 1994), and aids in determination of sources of classification errors (Fung and LeDrew 1988). The K for each map and classes with >18 sample sites were calculated using spreadsheet software and equations documented by Hudson and Ramm (1987), Rosenfield and Fitzpatrick-Lins (1986), Congalton et al. (1983), Rosenfield et al. (1982), and Cohen (1960). The swamp upland islands were not included in these points. Pair-wise comparisons between Ks of various classifications were calculated to determine significantly different error matrices, using the formula

$$Z=(K_1-K_2)/[V(K_1)+V(K_2)]^{1/2}$$

where K is the kappa coefficient, V(K) is the coefficient variance, and Z is the standard normal deviate. Significantly different K's (at the 95% confidence level) are indicated where $Z \geq 1.96$.

Agreement between the reference data and the classified map was also calculated for individual classes as a measure of categorical accuracy using the formula

$$K_c=(NX_{ii}-X_{i+}X_{+1})/(NX_{i+}-X_{i+}X_{+1})$$

where K_c is the accuracy measure for a given category, N is the total number of counts, X_{ii} represents matrix cell totals, and X_{I+} and X_{+I} represent row and column totals, respectively (Rosenfield and Fitzpatrick-Lins 1986). The categorical K was calculated only for those classes with a minimum sample size of 19. At this sample size, the probability that the map was correctly classified for a given class is 85% (Rosenfield et al. 1982).

Image Classification and Accuracy Results

Class composition and class areas for each map (11-, 13-, 17-, and 22-class maps) are detailed in Table 2-23. A list of vegetation species recognized in the classified image is given in Table 2-24. Blackgum (*Nyssa sylvatica* v. *biflora*), cypress (*Taxodium ascendens)*, and loblolly bay (*Gordonia lasianthus*) classes cover approximately 75% of the swamp. Error matrices for the 11-, 13-, 17-, and 22-class maps are found in Tables 2-25, 2-26, 2-27, and 2-28. The overall accuracies are 86%, 81%, 75%, and 67% for the 11-, 13-, 17-, and 22-class maps, respectively. Comparisons of the Ks for these maps showed that the 17-class map was not a significant (P=0.56) improvement in classification accuracy from the 22-class map (K_{22}=0.65, K_{17}=0.72); the 11- and 13-class maps (K_{11}=0.82, K_{13}=0.78) were significantly more accurate than the 22-class map (P_{11}=.0002, P_{13}=.0018), although the improvement was not significant when

consolidating from 17 to 13 (P=0.62) or 13 to 11 classes (P=0.22). Categorical Ks are given in Table 2-29. The blackgum, cypress, loblolly bay, wetland pine (*Pinus serotina*, *P. elliottii*), and shrub classes [titi (*Cyrilla racemiflora*), hurrahbush (*Lyonia lucida*), fetterbush (*Leucothoe racemosa*), Virginia willow (*Itea virginica*), dahoon holly *(Ilex cassine*), bamboo briar (*Smilax laurifolia*), Walter's briar (*Smilax walteri*), wax myrtle (*Myrica cerifera*), soapbush (*Clethra alterniflora*)], which constitute approximately 90% of the classified image area, had sample sizes sufficient for categorical calculations (K_c). Greatest categorical improvement occurred when consolidations were within blackgum, wetland pine, and loblolly bay classes, which cover 52% of the classified map. Pine (wetland and upland) and shrub classes were the most frequently misclassified categories, most often confused with blackgum and cypress classes (Table 2-30).

Although the overall accuracy for the 22-class map is only 67%, there are 15 classes with user's accuracies ≥75%, which means that the probability that a classified site is truly that class is ≥75%. Problematic classes make up 47% of the classified area, predominately mature bay-shrub, gum-bay-cypress-shrub, and scrub cypress-shrub. User's accuracies for those classes ranged from 0 (Pine-*Woodwardia*) to 69% (scrub-cypress-shrubs). In the 17-class map, with overall accuracy of 75%, there are 13 classes with user's accuracies ≥75%; 38% of the classified area contains classes that have lower accuracies (*Nuphar-Nymphaea*, gum-bay-cypress-shrub, *Smilax*-shrub, and bay-shrub). Improvement to ≥75% user's accuracy for these classes does not occur until they are consolidated to 11 classes. In the 11-class map, only gum-maple-bays (K_c=66%) has user's accuracy <75%.

Table 2-29. Categorical Kappa coefficients (K_c), user's and producer's accuracies for classes with >18 ground-truthed sites in the 11-, 13-, 17-, and 22-class classifications within 10 pixels (100 m) of sample location.

Map, Vegetation Class Name and Number	K_c (%)	User's Accuracy (%)	Producer's Accuracy (%)
11-Class Map			
Gum-Maple-Bays-Cypress-Shrub (3, 6)	61.9	66	100
Upland and Wetland Pines (1, 4, 7, 15, 21)	100.0	100	75
Briar-Shrub (9, 22)	81.9	85	73
Cypress-Shrub (2, 18, 19)	83.4	87	95
Loblolly Bay-Shrub (16, 17, 20)	75.1	79	90
13-Class Map			
Gum-Maple-Bays-Cypress-Shrub (3, 6)	61.9	66	100
Upland Pine (1, 4)	94.3	95	76
Wetland Pine (7, 15, 21)	74.1	78	56
Briar-Shrub (9, 22)	81.9	85	73
Cypress-Shrub (2, 18, 19)	83.4	86	95
Loblolly Bay-Shrub (16, 17, 20)	75.1	79	90
17-Class Map			
Upland Pine (1, 4)	94.3	95	76
Wetland Pine (7, 15, 21)	74.1	78	56
Cypress-Gum-Shrub (18, 19)	83.2	87	95
Shrubs (22)	76.2	79	65
Gum-Bay-Cypress-Shrub (6)	40.9	44	100
Bay-Shrub (16, 17)	56.5	60	75

Map, Vegetation Class Name and Number	K_c (%)	User's Accuracy (%)	Producer's Accuracy (%)
22-Class Map			
Gum-Bay-Cypress-Shrub (6)	40.9	44	100
Mature Cypress-Shrub (18)	72.1	76	81
Shrub (22)	76.2	79	65

Table 2-30. Class confusions in the 11-, 13-, 17-, and 22-class classifications within 10 pixels (100 m) of sample location, for classes with user's accuracy <80%. The class with most frequent error is underlined.

Map, Vegetation Class Name and Number	**User's Accuracy (%)**	**Class Confusions Occurring in Map**
11-Class Map		
Gum-Maple-Bays-Cypress-Shrub (3, 6)	66	Pines, <u>Shrubs</u>, Cypress-Shrub, Loblolly Bay-Shrub
Loblolly Bay-Shrub (16, 17, 20)	79	<u>Pines</u>, Shrubs
13-Class Map		
Gum-Maple-Bays-Cypress-Shrub (3, 6)	66	Wetland Pine, <u>Shrubs</u>, Loblolly Bay-Shrub, Cypress-Shrub
Water Lilies (5)	50	Carex-Nymphaea
Wetland Pine (7, 15, 21)	78	Upland Pine
Loblolly Bay-Shrub (16, 17, 20)	79	<u>Wetland Pine</u>, Shrubs
17-Class Map		
Nuphar-Nymphaea (5)	50	Carex-Nymphaea
Gum-Bay-Cypress-Shrub (6)	44	<u>Gum-Maple-Bays</u>, Wetland Pine, Bay-Shrub, Cypress-Gum-Shrub, Mature Loblolly Bay, Shrub
Wetland Pine (7, 15, 21)	78	Upland Pine
Briar-Shrub (9)	57	Upland Pine, Wetland Pine, Shrubs
Loblolly Bay-Shrub (16, 17)	60	<u>Wetland Pine</u>, Mature Loblolly Bay, Shrub
Loblolly Bay (20)	77	<u>Bay-Shrub</u>, Shrub
Shrub (22)	79	Wetland Pine, Briar-Shrub
22-Class Map		
Pine-Palmetto (4)	75	100% Upland Pine, Pine-Gum-Bay
Nuphar-Nymphaea (5)	50	Carex-Nymphaea

Table 2-30--continued.

Map, Vegetation Class Name and Number	**User's Accuracy (%)**	**Class Confusions Occurring in Map**
Gum-Bay-Cypress-Shrub (6)	44	Gum-Maple-Bays, Pine-Gum-Bay, Young Bay-Shrub, Mature Cypress-Shrub, Scrub Cypress-Shrub, Mature Loblolly Bay, Shrub
Pine-Gum-Bay (7)	58	Pine-Palmetto, Pine-Woodwardia, Wetland Pine
Briar-Shrub (9)	57	Pine-Palmetto, Wetland Pine, Shrub
Pine Woodwardia (15)	0	100% Upland Pine, Pine-Palmetto, Pine-Gum-Bay
Mature Bay-Shrub (17)	50	Pine-Gum-Bay, Young Bay-Shrub, Mature Loblolly Bay, Wetland Pine, Shrub
Mature Cypress-Shrub (18)	76	Pine-Gum-Bay, Smilax-Shrub, Open Water, Scrub Cypress-Shrub, Shrub
Scrub Cypress-Shrub (19)	69	Pine-Woodwardia, Mature Cypress-Shrub
Mature Loblolly Bay (20)	77	Young Bay-Shrub, Mature Bay-Shrub, Shrub
Wetland Pine (21)	75	100% Upland Pine
Shrubs (22)	79	Pine-Gum-Bay, Briar-Shrub, Pine-Woodwardia

Reference sites with producer's accuracy $\geq$75% in the 22-class map (12 classes) included those comprising approximately 80% of the swamp. This indicates that the reference pixels for the classes covering a greater proportion of the swamp were fairly accurate examples of those vegetation types. The 10 classes with lower producer's accuracy are pine, loblolly bay, and shrub classes that are consolidated in the 17-, 13-, and 11-class maps. Only the open water and shrub classes, with producer's accuracies of 50% and 73%, respectively, remain <75% accurate in the 11-class map. This is probably because of location error; one of the open water sites was in a cypress pond and was misclassified as the surrounding cypress class. The shrub class often occurs in the matrix among blackgum, cypress, and loblolly bay classes, where an error of 50 m could result in a perceived location in a different vegetation class.

Although island ground-truth points were not included in the original classification, it was recognized that errors probably existed in these areas. The swamp upland island area classification was improved with the subset and reclassification. Accuracies in the reclassification area are reported in Table 2-31.

Interpreting the Accuracy Assessment

User's and producer's accuracy statistics can be used in map interpretation to identify classes with greater error likelihood. Map interpretation is aided by knowing the causes of classification errors. Misclassifications may be the result of location error (difference between ground-truthed location and map location), observer bias when estimating proportions, or man-induced changes in the site between the image capture

Table 2-31. Error matrix of classes in the swamp-and-island-uplands map that are combined with those in the 17-class map. Cell values are number of samples re-classified in the swamp-and-upland-islands classification from classes in the 17-class map.

Vegetation Class	Pine-Cypress-Hardwoods	Mixed Upland and Wetland Shrubs	Sparse Pine	Dense Pine	User's Accuracy (%) [a]
17-Class Map					
Bay-Shrub	1	1	4	4	10
Upland Pine			6		100
Wetland Pine			6	4	100
Shrubs			2	1	0
Sedges-Ferns-Water Lilies	2		2		0
Briar-Shrub		2			100
Cypress-Gum-Shrub	3		2	2	43
Gum-Bay-Cypress-Shrub	1	1			50
Loblolly Bay					100
Gum-Maple-Bays			1		0
Producer's Accuracy (%)	75	100	52	57	

[a] Overall accuracy of additional classes in swamp and island uplands map= 75%.

and ground-truthing dates. Identifying these types of errors requires recognition of the likely successional sequence, awareness of typical land use practices that might change the landscape composition, such as clear cutting and re-planting timber, and familiarity with the region and vegetation being classified.

Errors that occurred in the 1990 swamp image classification usually involved pine, shrub, and mixed blackgum classes. Most classes on the image contain some proportion of pine and shrub; if the location was in error or if the patch was not evenly dense and this was detectable at the 10 m pixel level, then the pine and shrub classes may have been recorded. The mixed blackgum classes are combinations of many species. When blackgum classes are highly interspersed with other classes, and location error occurs, the classes may be misidentified. Errors in the upland island classification also involved confusions of pine and shrub classes. Island classes were delineated and identified by refuge foresters. Although they would like to distinguish among pine densities and interspersion with hardwoods, there may have been insufficient differences in spectral signatures of these types because of species interspersions in their selected reference sites. Delineation of upland pine and shrub community types may be possible only between "pine" (where pine-cypress-hardwoods and dense and sparse pine classes are combined) and "not pine" (represented here by grasses and shrubs).

The most accurate maps were the 11- and 13-class maps, which were not significantly different. Accuracy of the 11- and 13-class maps were significantly better when searching a radius of 100 m than 35-50 m for specific class types. The number of correctly classified sites on the 22- and 17-class maps did not depend on this search

radius. Map complexity or patch interspersion may affect perceived map accuracy; the map may actually be correct, but location error misplacing an observer on the ground suggests map error. Reporting map accuracy by distances of search radii around the target pixel(s) incorporates information about the location error of ground-truthed sites, and aids in identifying if the error is a true classification error, the result of class patchiness, or due to location error.

Applying Image Classification Procedures

Using a classification scheme based on spectral rather than textural qualities also aided in the classification accuracy. The spatial complexity of the swamp vegetation requires this fine data resolution; swamp and upland island vegetation communities occur in a mosaic rather than in large, single-species patches. Detection of the interspersed vegetation types is compromised at the 30 m pixel level. Even with 10 m pixels data are lost; details at sub-pixel level are not detectable, which must be considered when assessing vegetation community changes over time. This spatial complexity also affects map accuracy. Although the map accuracy assessment can be automated, the ground-truthed sites should be examined on the image to identify the types of errors occurring e.g., location error, class confusion, class overlap.

A thorough understanding of the classification process is necessary to use the classified map properly. For this image classification there were several upland classes that did not occur in the wetland part of the swamp. These classes were eliminated from the training set used to classify the swamp proper, which was extracted from the image

and then stitched back to the perimeter area after classifying. Selecting a reduced signature set was also necessary in the matching region, where the north and south images were joined. The classification accuracy would have been improved initially by selecting training sites isolated on the large islands. These islands contain upland shrub species [saw-palmetto (*Serenoa repens*), gallberry (*Ilex glabra*), blueberry (*Vaccineum* spp.), oak (*Quercus* spp.)] not found in the wetland environment; because they were not included in the original training signature set, the classified map shows shrub communities on the islands, but their species composition differs from those in the swamp. Other classification errors such as confusing classes, could be remedied in an iterative process of classifying, ground-truthing, re-classifying, ground-truthing, etc., which was cost-prohibitive in this study. Change assessments must recognize if this type of classification signature set manipulation has occurred, so that changing class composition and distribution are recognized only where they occurred naturally.

Selection of representative signatures in developing the training set for supervised classification requires a thorough knowledge of the area of interest. Since the classification will be forced to assign pixels to the specified class selection, the signatures must be typical of all classes present. This is facilitated by beginning with an unsupervised training site selection and image classification, and using the results to locate class types and locations for ground-truth identification. The process can then be repeated using those ground-truthed sites in supervised classification seed set selection and the supervised classification of the image. Subsequent ground-truthing will provide data for an accuracy assessment. Time and budget limitations prevented ground-truthing

more than one set of sites. Rutchey and Vilcheck (1994) found that the spatial heterogeneity of the Everglades, which is probably similar to that of Okefenokee Swamp, limited the number of classes in their unsupervised classification; they used a minimum class patch size of a 3x3 pixel (60 m X 60 m) window to eliminate classes that occurred only in smaller patches. Because some categories did not occur in patches greater than 60 m X 60 m, they overlooked some classes. They suggest beginning with a large number of classes, without the patch size restriction, and combining them until the desired accuracy is achieved. This is essentially the procedure followed in this supervised Okefenokee classification.

Class consolidation involves combining mixed and/or single species classes. In this classification groups with similar species but different proportions were combined when the maps were consolidated. Accuracy improvements were not significant for the consolidation from the 22-class map to the 17-class map, but improvements were significant for the 17- to 13- and 17- to 11-class combinations. The groupings from 22 to 17 classes concerned some mixed species classes, but left some classes with the same dominants separate. The accuracies of these classes improved when lumped in the 13-class map. These groupings involved mixed species and ages with the same dominant but different sub-dominant species (e.g., young loblolly bay-shrub combined with mature loblolly bay-shrub and mature loblolly bay). Upland island classification accuracy would also have improved by combining the pine-dominated classes into one class. Even the more homogeneous classes are complex enough to cause some confusion with mixed

classes in a 10 m pixel image due to location error. The highly interspersed matrix requires a small location error to correctly assess classification accuracy.

The limitations of imagery to detect sub-pixel changes must be recognized in change detection studies. Aerial photograph resolution may permit identification of more detail than from SPOT 10 m resolution imagery. Interpretation of aerial photography includes spectral as well as textural information, which can aid in class identification. Definition of edges in satellite imagery is difficult where mixed class composition varies. Stereo color infrared aerial photographs may be better tools than imagery for mapping the mixed classes, since species details may be discernable at the sub-pixel (100 m^2) scale. However, spatial registration of photographs may be difficult due to photograph distortion and absence of reference features in wilderness areas (see Chapter 4). Imagery is more easily geo-referenced due to its greater spatial extent and likelihood of including landscape features suitable for registration. Additionally, satellite image data provide a large amount of information which can be rapidly processed using computer discriminated vegetation types. Detection of changes in community composition and distribution might be most accurate when aerial photographs and satellite images are interpreted together (Silveira 1996).

The maps produced here are sufficiently accurate for change detection study within the swamp if the following are recognized:

1) The classification procedure selectively included classes in the signature set; absence of a class in a particular area could be due to its exclusion from the signature set, although signature eliminations were done primarily for highly unlikely classes (e.g.,

upland classes removed from classification of wetland areas and wetland classes removed from upland areas).

2) Classes are not equally accurate; shrub, pine, and blackgum classes may be confused with other mixed species classes, and classes based on species' densities may be misidentified.

3) Detectable changes with satellite imagery will be limited to the scale of 10s of meters given the image pixel size (10 m). Aerial photography should be used to detect changes at the sub-pixel level.

CHAPTER 3
OKEFENOKEE SWAMP HYDROLOGY MODEL

Introduction

The Okefenokee Swamp hydrologic environment has a history of manipulation. Although indirect impacts to the hydrology were occurring as settlements arose in the surrounding landscape and wildfire control, prescribed burning, grazing by domestic stock, and timber harvest were increasingly practiced during the 18^{th} and 19^{th} centuries, it was not until 1890 that the direct assault began (Trowell 1989c). Attempts to drain the swamp failed, but the excavation left a 20 km ditch (the Suwannee Canal) connecting the eastern shrub and prairie environments to the western river system. The extensive logging following the drainage attempt removed timber from 26% of the landscape (see Chapter 4), and the composition and structure of vegetation in the landscape changed with vegetation regrowth (see Chapter 4). Inhabitation of the surroundings increased the perceived need to control wildfire, which was a vital process in the dynamics of the swamp and the perimeter upland vegetation communities. In response to personal property and perceived ecological damage caused by widespread fires in 1954-1955, the Suwannee River Sill was constructed in 1960 to impound the swamp and protect it from future drought and fire (Chapter 742, Public Law 81-810, 70 Statute 668). The decades

that followed did not show a decrease in fire frequency (see Chapter 5), and the realization by swamp managers and ecologists that wildfire was integral to the system's health challenged the declared purpose of the Suwannee River sill. In 1990 review of the sill's purpose and actual effect on the swamp hydrologic environment and vegetation communities was determined necessary, before repairs or changes to the decaying structure could be recommended (Roelle and Hamilton 1990). A spatial computer model would provide temporal and spatial information about the Sill's area and degree of effect on swamp hydrology, and permit manipulation of the swamp landscape and hydrologic features to identify the system's sensitivities. It was for those purposes that the hydrology model discussed herein was developed.

This chapter discusses development of the spatial model of the Okefenokee Swamp hydrologic environment (HYDRO-MODEL), manipulations of model parameters that suggest system sensitivities, indications of the Sill's impact area, and extent of effects of the existing Sill identified with model manipulations. Model application and analyses focus on the following questions: 1) Has the sill changed the swamp hydrologic environment? If so, where and how have these changes occurred? 2) Have vegetation changes reflective of the sill's influence occurred disproportionately in the area affected by the sill? 3) Have wildfire size and frequency changed in the area impacted by the sill? 4) What changes in swamp hydrology and vegetation distributions can be anticipated with the sill's removal? Model code and detailed instructions for implementation are included in Appendix B. Development of model databases are briefly discussed in this chapter, and in detail in Chapter 2.

Methods

Model Objective

The Okefenokee Swamp hydrology model was developed with weather and vegetation data representing conditions in the swamp during 1980-1993, and topographic information collected during 1991-1994. The model is intended to represent the swamp hydrology cycling in twice-monthly time steps during 1980-1993, and provides output in sample point form and water surface elevation and depth maps of the Okefenokee National Wildlife Refuge area for each process interval. Output data include water depth, water surface elevation, and amount of water moved in each time step, and can be viewed by individual interval, in a "movie" of the entire process period by monthly intervals, and queried as entire maps or individual cell values. The model was built and calibrated using data from 1980-1993, and run with independent data sets for decade intervals of 1941-1949, 1950-1959, 1960-1969, and 1970-1979 to assess model performance. The "with-" and "pre-sill" conditions (1960-1993 and 1941-1959, respectively) were represented by topographic surfaces with and without the sill in place. Data from 1980-1993 were also applied in the model to the no-sill topographic surface to demonstrate water surface elevations that might have occurred during that period had the sill been absent. The model is a predictive tool in that input data grids can be modified to reflect potential changed conditions (such as no sill, no ET, no precipitation) and output grids compared, and it should be used to examine trends in water surface

elevations over time. The model can not predict future conditions since it relies on actual, recent flow, evapotranspiration, and precipitation data summarized semi-monthly. Examination and comparison of current weather and swamp hydrology, and trends and conditions during previous months, seasons, or years should provide an indication of the potential swamp hydrologic environment that could be expected during any month with various weather conditions. Its use in this study was not to predict the current or future swamp hydrologic environment, but to identify the region of the sill's impoundment effects and how the recent hydrologic environment of the effected area might have differed in the sill's absence.

Model Overview

HYDRO-MODEL is written in ARCINFO Macro Language (AML) (version 7.0, ESRI, Inc., Redlands, CA 92373) routines to operate in the ARCGRID Unix environment. The complete model text is provided in Appendix B. The model is a grid-cell model that processes within the Okefenokee National Wildlife Refuge boundaries. Each cell in the landscape encompasses 250,000 m^2 (500 m x 500 m); 10,672 cells are modeled (Figure 3-1). After the model initiates processing by setting user-defined parameters and interval dates, several processes occur within each cell (Figure 3-2) during 3 main model phases. In Phase I a water surface is created (inh20*xxx*, where *xxx* specifies the year, month, and interval for processing) by combining a starting water depth that is defined either by the decade starting date or created in the final processes of the previous interval's Phase III, the swamp topographic surface elevation, and inflowing

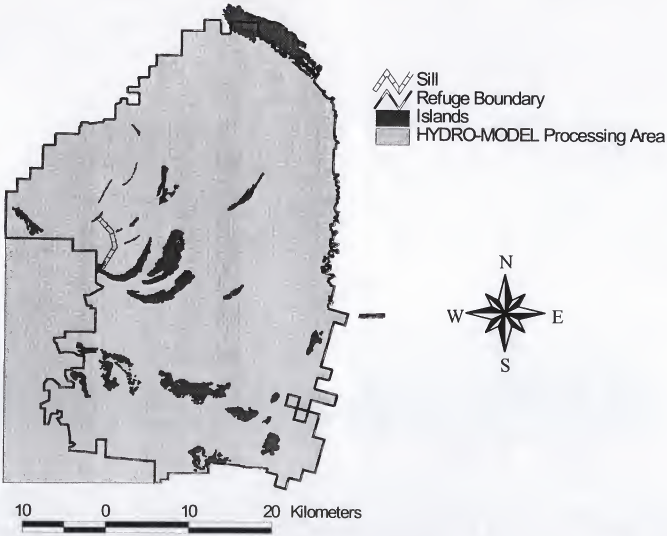


Figure 3-1. Processing area for the Okefenokee Swamp HYDRO-MODEL.

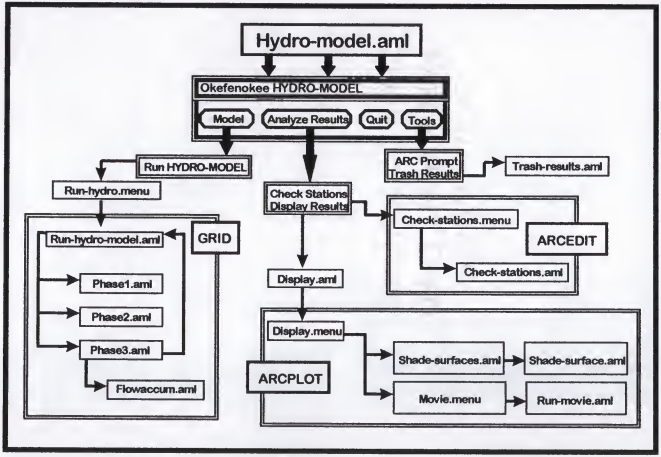


Figure 3-2. Flowchart of Okefenokee Swamp HYDRO-MODEL components.

water from perimeter creeks. Creek or river outflow are removed from appropriate cells and evapotranspiration occurs in each cell, creating a net water surface (net*xxx*, where *xxx* specifies the year, month, and interval for processing) in Phase II (Figure 3-2). Surface sheetflow occurs in Phase III. If the water surface is sloped, determined by the topographic surface elevation, water depth, and a query of neighboring cells (Figure 3-3), water is moved to the neighboring cell with the lowest elevation. The amount of water moved in this step is determined by a subroutine that identifies how much water should move in and out of each cell based on local elevation gradients. If a gradient is flat, no water movement occurs in that cell's immediate neighborhood. The model processes this sequence for a user-defined number of iterations ("# of pixels to move water" in the model interface, Figure 3-4) . This permits water to move more than one cell length in a semi-monthly interval, or to move at single cell lengths if data are provided for shorter model iterations. The final model products of Phase III are ending water surface elevation (ewat*xxx*) and water depth (dwat*xxx*, where *xxx* specifies the year, month, and interval for processing) for the specified interval. The water depth surface (dwat*xxx*) then becomes a starting surface for Phase I of the next model iteration.

Several modifying grids were added to the basic processing steps listed above to refine water movement in the swamp landscape. Inflow into the swamp occurs primarily in the Northwest from streams that flow continuously but with seasonal fluctuations. Water from these streams most likely flows along the topographic gradient on the western swamp to the Suwannee River and does not cross over to the eastern swamp because of topographic slope. Therefore, to direct movement of this water that originates

Start at cell address 0,0:

1) **Check flow movement direction at each neighboring cell address.**
2) **Sum water moving into 0 from each neighbor.**
3) **Move to cell 1,0.**
4) **Repeat across entire grid for "pixels-to-move-water" iterations.**
5) **Report "amt-to-move".**
6) **Return to Phase 3.**

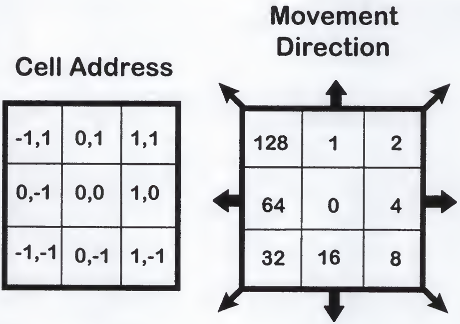


Figure 3-3. Neighborhood search in HYDRO-MODEL to determine direction and amount of water to move in each cell and time interval.

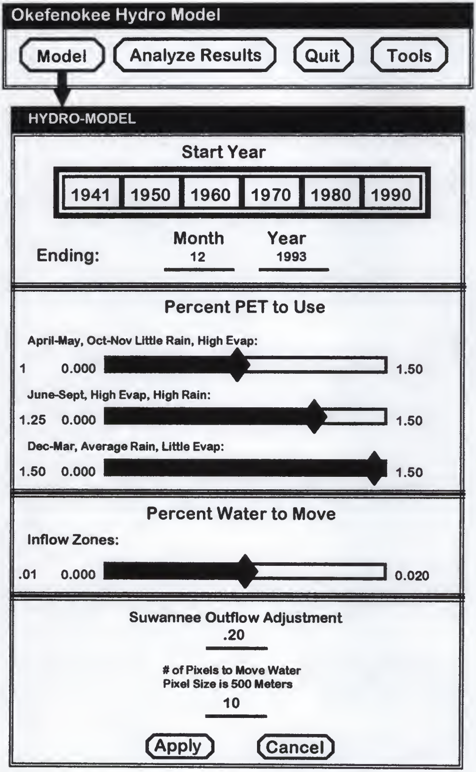


Figure 3-4. HYDRO-MODEL menu interface for setting user-defined parameters.

in the Northwest creeks and flows through the western swamp and river floodplain, zones were created (Figure 3-5); in each model iteration the estimated flow into each zone, representing inflow by creek drainages, is proportioned equally among the zone's cells. This permits movement of the entire inflowing volume through the landscape with each model iteration.

Outflow is similarly proportioned in an outflow zone near the Suwannee River Sill (Figure 3-6), and removed in each interval. Outflow zones for other exiting flows (St. Marys River, Cypress Creek, and Sweetwater Creek) are also coded into the model so that flow volumes can be incrementally removed; however, topographic gradient was used to move water in these areas in the model iterations discussed here, and the creek outflow zone code was bypassed. Water also flows over the sill, directed by the surface gradient. The estimated flow volume in the inflow and outflow zones can be adjusted by proportional multipliers (for inflow, "Percent Water to Move", and for outflow, "Suwannee Outflow Adjustment"), to fine-tune the model performance (Figure 3-4). Although a constant setting seemed appropriate for the inflow proportion, the Suwannee River outflow proportion varied with processing decade (see model results discussion). Flow rates were also varied by vegetation type (shrub, forested, open water, prairie) and a manning's coefficient, which affects the flow rate depending on the substrate type (Table 3-1). Proportional adjustments to the estimated evapotranspiration volumes were also included to vary seasonal evapotranspiration rates, if necessary (Figure 3-4, "percent PET to use" in the model's user interface).

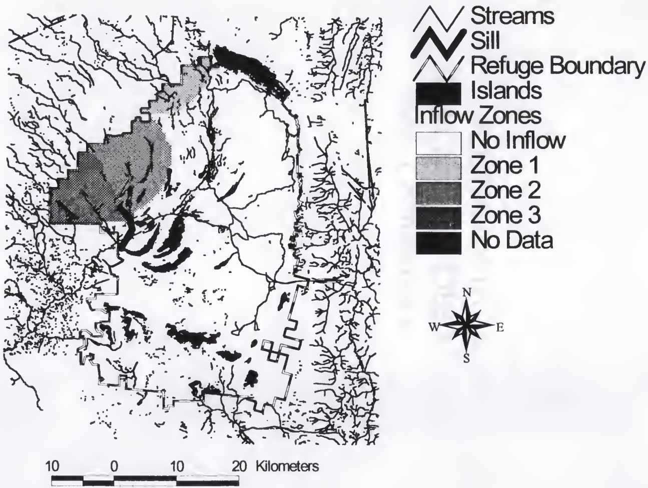


Figure 3-5. Locations of zones used in HYDRO-MODEL to distribute inflowing water across the landscape.

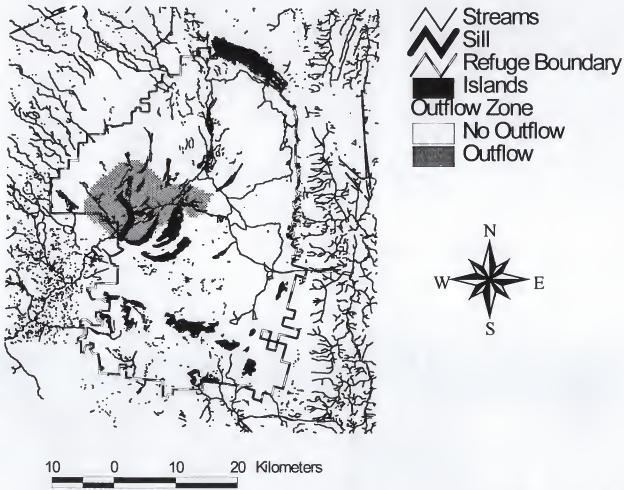


Figure 3-6. Location of zone used in HYDRO-MODEL to extract outflowing water from the Suwannee River floodplain.

Table 3-1. Manning's roughness coefficients used in HYDRO-MODEL to adjust surface water flow rates over various substrates (adapted from Ward (1996)).

Substrate or Vegetation Type[a]	**Manning's Coefficient**
Lawn, Agricultural Field	0.03
Bare Ground, Urban Development, Road	0.025
Clearcut, Sparse Pine Forest	0.045
Upland Forest	0.08
Wetland Forest	0.15
Wetland Shrub	0.13
Wetland Prairie	0.10
Submerged Aquatic Vegetation	0.07
Open Water, unvegetated	0.065
Ditch with grass banks	0.027
Impoundment	0.02
Canoe Trail, unvegetated peat	0.07
Canal	0.065
Riverbed, unvegetated	0.047
Stream bed, unvegetated	0.10

[a] Manning's coefficients were assigned to topographic features (e.g., stream, lake) first, vegetation type second, where appropriate.

Model Data Sources

Origins of HYDRO-MODEL point data sets are discussed in detail in Chapter 2. A brief overview of their purposes, sources, and conversion to spatial data sets is presented here.

Precipitation

Precipitation data were compiled from recording stations installed and maintained by NOAA, the Okefenokee National Wildlife Refuge, and supplemental recorders installed in this study. Biweekly precipitation totals were calculated and missing data were estimated using regression relationships developed as detailed in Chapter 2. The biweekly point data were converted to spatial grids using interpolation algorithms in ARCINFO. Several methods provided by ARCINFO and ARCGRID were applied to the point data, and a methodology combining the techniques was chosen. Data from each biweekly interval were first interpolated with kriging and the circular algorithm, selected after viewing interval semivariograms and determining that in general, the most realistic surfaces were calculated with this algorithm (Burroughs 1986). Where insufficient data densities prohibited using this method, the point data were interpolated using the ARCINFO-TINNING command (ESRI 1992) with the quintic algorithm, and then gridded to 500x500 m cells. The resultant precipitation data surfaces were stored in a directory and accessed individually during model processing.

Evapotranspiration

Biweekly evapotranspiration point data were estimated from temperature data collected daily at NOAA weather stations, as detailed in Chapter 2. Procedures to calculate data surfaces followed those detailed for precipitation data. Evapotranspiration estimates were modified with a multiplier to account for differential rates in major vegetation types, and a user-defined coefficient was added to the model interface to seasonally adjust evapotranspiration rates (Figure 3-4).

Creek Inflow Volumes

Surface water flow into the swamp is concentrated along the northwestern perimeter (Figure 2-24). Creek inflow volumes at selected locations were estimated as detailed in Chapter 2. Volumes representing biweekly flow estimates were converted to sheetflow by proportional dispersion across inflow zones delineated using the swamp vegetation and topographic maps as guides of zone boundaries (Figure 3-5). Distribution of inflows into regions rather than from perimeter points reflected Blood's (1981) conclusions that the bifurcation ratio of the northwestern inflowing streams was indicative of a low relief, coastal plain where loosely defined stream channels and branching are common. This implies that water movement into the swamp can be represented as sheetflow rather than as point inflow sources. Therefore, each cell in the input zone grid received a proportion of the biweekly, total volume inflowing from northwestern perimeter creeks, in Phase I of the model. A user-defined coefficient to uniformly modify this proportion was also added to the model interface to facilitate adjustment (Figure 3-4). Biweekly inflow data are stored in a data table (IN4193) and

are applied to the appropriate zone grid as identified in an INFO table item (INFLOW). Because groundwater contribution to the total swamp water budget is minimal (Rykiel 1977), it was not included as a separate model parameter but included in the surface inflow volumes.

River Outflow Volumes

Volumes of water leaving the refuge via the St. Marys River, Suwannee River, Cypress Creek, and Sweetwater Creek were estimated as detailed in Chapter 2. Biweekly flows were converted to sheetflow by proportional dispersion across outflow zones delineated using the swamp vegetation and topographic maps as guides of zone boundaries (Figure 3-6). Each cell in the zone grid received a proportion of the total outflowing volume in Phase I of the model. A user-defined coefficient to uniformly modify this proportion in the Suwannee River outflow zone was also added to the model interface to facilitate adjustment (Figure 3-4). Biweekly outflow data are stored in a data table (OUT4193) and are applied to the appropriate zone grid as identified in an INFO table item (OUTFLOW). Only the Suwannee River outflow volume was removed in the model iterations discussed here. Although the model includes instruction to similarly remove outflow from the other exiting flows, the topographic gradient was used to force directional flow in these areas. Groundwater outflow was assumed to be a minimal component of the total swamp water budget (Rykiel 1977), and therefore it was included in the outflow estimate instead of as an independent model parameter.

Water Depth and Topographic Surfaces

Direction of water movement through cells in the swamp landscape (outside of inflow and outflow zones) is determined by the surface topographic gradient. Topography grid development is detailed in Chapter 2. Starting water depth grids estimated for the first interval of each decade are retrieved by the model and added to the topography surface to create a starting water surface elevation grid (Figure 3-2, Phase I). Creation of the water depth grids is detailed in Chapter 2. Movement of water among grid cells in the water surface elevation grid is accomplished with a neighborhood query and summation (Figures 3-2 and 3-3, Phase 3), and modified with a Manning's coefficient (Table 3-1) to allow for differential movement of water across varying substrates (Ward 1995). The ending water depth grid is created by subtracting the topographic surface elevation grid from the water surface elevation grid, and the resultant depth in Phase 3 becomes the starting water depth in Phase 1 of the subsequent interval (Figure 3-2).

Data Surfaces Used for Model Assessment

At the end of the completed model run, an assessment of model performance was made using water depth estimates extracted from 30 cells corresponding to water level recorder locations (Figure 3-7). The subroutine "Check Stations" (Figure 3-2) extracted the station name, date, water surface elevation, and water depth for each interval and created an ASCII file that could be imported into a spreadsheet program to plot against recorder data. The entire water depth, water surface elevation, and water movement grids could also be examined using the "Display Results" subroutine (Figure 3-2) to view

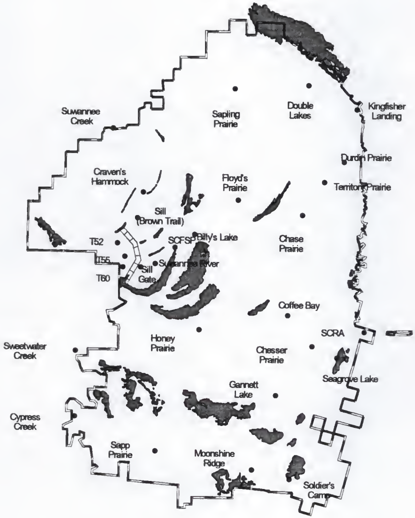


Figure 3-7. Locations of water level recorders used to assess HYDRO-MODEL performance.

spatial relationships among the recorder location data and the surrounding swamp landscape. Subsequent adjustments to the model code were based on these visual comparisons.

Model Manipulation and Assessment

The primary objective of this study was to determine if the sill is affecting the swamp hydrologic environment, and if so, to what spatial and temporal extent. Manipulations of the model code and swamp topographic surface provided initial indications of the sill's impacts. The model was constructed using a topographic surface representing the "with-sill" condition during 1980-1993 (Figure 2-20). This surface was replaced with a "no-sill" topographic surface (Figure 3-8) and model variables set at "pre-sill" levels to estimate the swamp hydrologic environment during 1980-1993 in the sill's absence. Similar conditions were set for 1960-1969 and 1970-1979 data and the "no-sill" topographic surface to assess possible changes in swamp hydrology that might be attributed to the sill. The model was also manipulated with 1941-1949 and 1950-1959 data. The topographic surface including the sill was used, with model parameters set at "with-sill" levels, to approximate conditions that might have existed with the sill in place. Model sensitivity to changing water volume was also assessed. In separate model runs the total Suwannee River outflow was also retained in the swamp during each decade to determine the maximum impoundment levels possible. Additional model manipulations included incremental increases and decreases in Suwannee River outflow, evapotranspiration volumes, and volumes of creek inflow to assess responses in the 1980-1993 swamp environment.

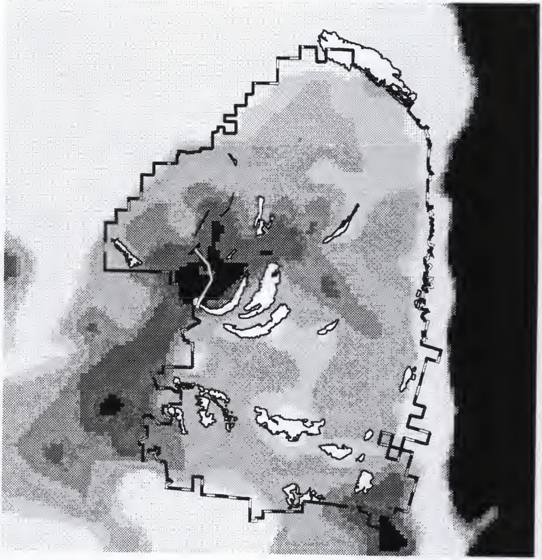


Figure 3-8. Estimated topographic surface representing the pre-sill peat surface elevations. Dark areas are low in elevation.

After each model manipulation the "Check Stations"summary file was created and imported into a spreadsheet to graphically compare with other model manipulation results. Since the model was constructed using recorder data from 1980-1993, model performance was best during that decade. Disagreements between model estimates and estimated recorder data for 1941-1979 may be a function of system changes (e.g., topography, inflow volumes, vegetation distributions) or missing data extimation techniques, and not necessarily indicte a poor model performance. Therefore, model manipulations during 1941-1979 were exploratory, while those for 1980-1993 were used to identify the sill's influence on the system. Decade and growing/nongrowing season hydroperiods were also calculated from "with sill" and "no sill" model results, and contingency tables (log-likelihood ratio, G-statistic) (Sokal and Rohlf 1981) were used to determine where hydroperiod frequencies differed significantly. Changes in relationships between the sill area water depths and those at stations throughout the swamp under high, average, and low water level conditions were assessed by comparing coefficients of variation and slopes of regression relationships. These assessments provided clues to the spatial and temporal extent of the sill's effects, and variability of these effects with overall water level conditions.

Wildfires in the Area Affected by the Suwannee River Sill

The primary purposes of the Suwannee River Sill were to facilitate wildfire control by creating impounded conditions during periods of drought, and to arrest the spread of wildfires across the landscape by prolonging inundation. Refuge records

contain information primarily on fires that were controlled by fire suppression intervention and not on those that were initiated and naturally extinguished before detection. Therefore it is not possible to determine if the sill affected total fire occurrence. However, it is possible to determine if the sill was elevating water levels during seasons of high fire frequency, if fires were arrested in the sill impact area due to elevated water levels, and if reported incidences of wildfires decreased following sill construction. These questions were addressed by comparing maps of wildfire ignition location and burn extent with a delineation of the sill-affected area, and information on general hydrologic conditions at the time of the wildfires, summarized from the water level recorder database and model output surfaces. Comparisons were made using IMAGINE (version 8.2, ERDAS, Inc., Atlanta, GA 30329) summaries and overlays and ARCVIEW map inqueries.

Vegetation in the Area Affected by the Suwannee River Sill

The Okefenokee Swamp vegetation landscape is dynamic. Fluctuations in species compositions and distributions may be the consequences of naturally occurring community succession, but may also result from historic logging, wildfire management, or manipulations of the landscape hydrology. Comparisons in vegetation distributions relative to logging history and wildfire history are detailed in Chapters 4 and 5, respectively. Changes that might be attributed to hydrologic modifications of the Suwannee River Sill are summarized in this chapter. Areas of vegetation change determined in Chapter 4 were compared with ERDAS-IMAGINE summary overlays of

the estimated sill impact area. Proportions of vegetation types within and outside of the affected area were estimated and compared between the areas.

Results

Area Affected by the Suwannee River Sill

Although varying with precipitation and evapotranspiration volume, the northern and eastern extent of the Suwannee River sill's effects are roughly delineated by Craven's Hammock to Floyd's Prairie to southeastern Chase Prairie to the Pocket (Figure 3-9). Since sill construction, this region has experienced elevated water levels and/or extended hydroperiods that have not occurred elsewhere in the swamp. The sill has also affected vegetation composition and distribution in this area, which were previously altered by logging and fire suppression. Discussion of changes in the swamp hydrologic environment and vegetation distributions indicated by the hydrology model output follows.

Model Accuracy: 1980-1993

Model performance was assessed at 28 stations distributed throughout the swamp (Figure 3-7); model data and trends at 20 of these stations generally followed recorder data (Figure 3-10). These 20 stations were used to ascertain effects of additional model manipulations. The remaining 8 stations elucidated various problems with the model (Figure 3-11). Excessive water depths at perimeter or near-perimeter stations were

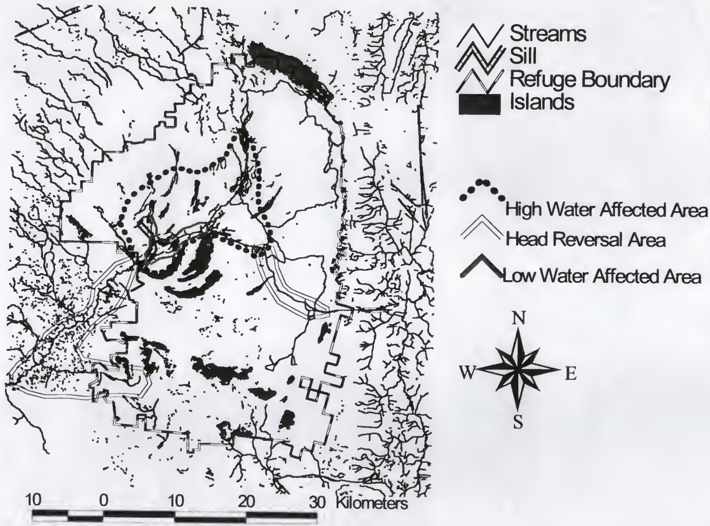


Figure 3-9. Estimated area of impact of the Suwannee River sill on the Okefenokee Swamp hydrologic environment during various water level conditions, and regions that may experience head reversals when water levels are high.

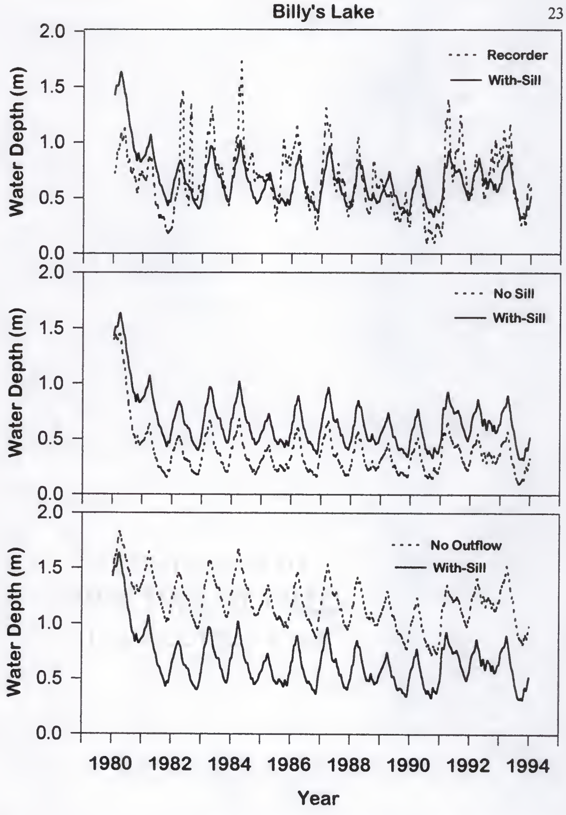
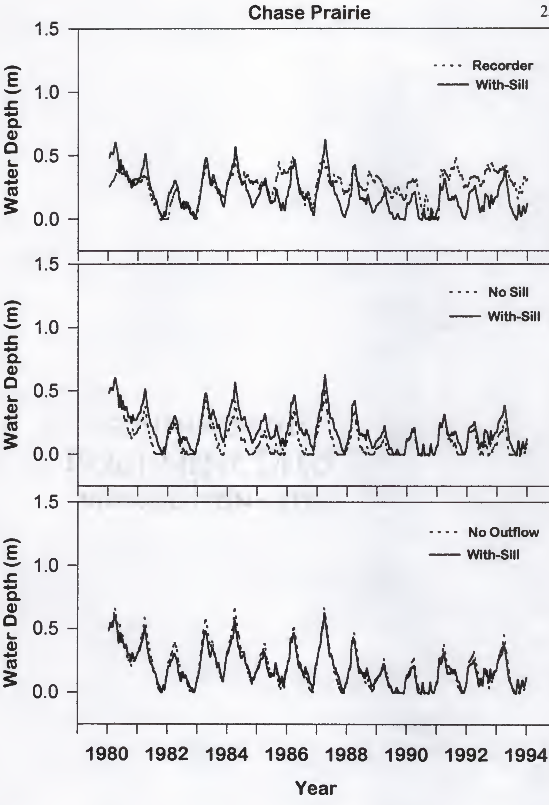


Figure 3-10. Estimated recorder data and model output from the "with-sill" and "no-sill" simulations for 1980-1993.



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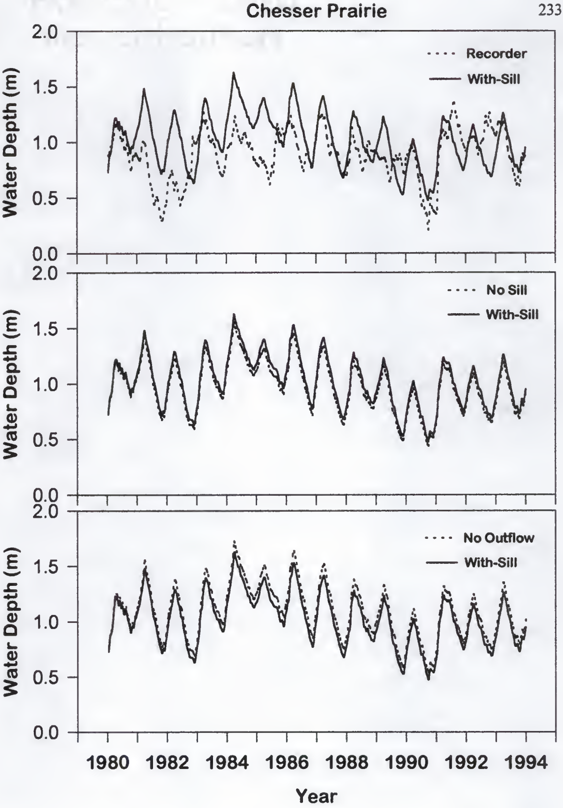

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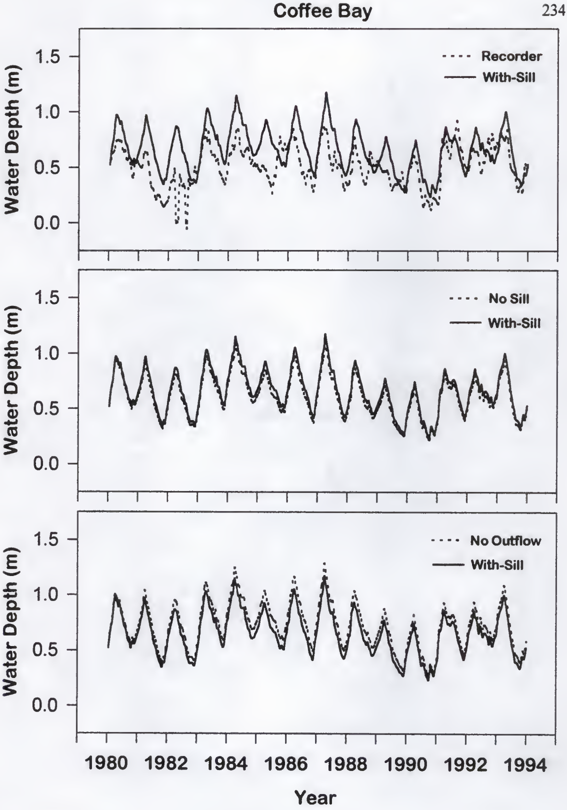

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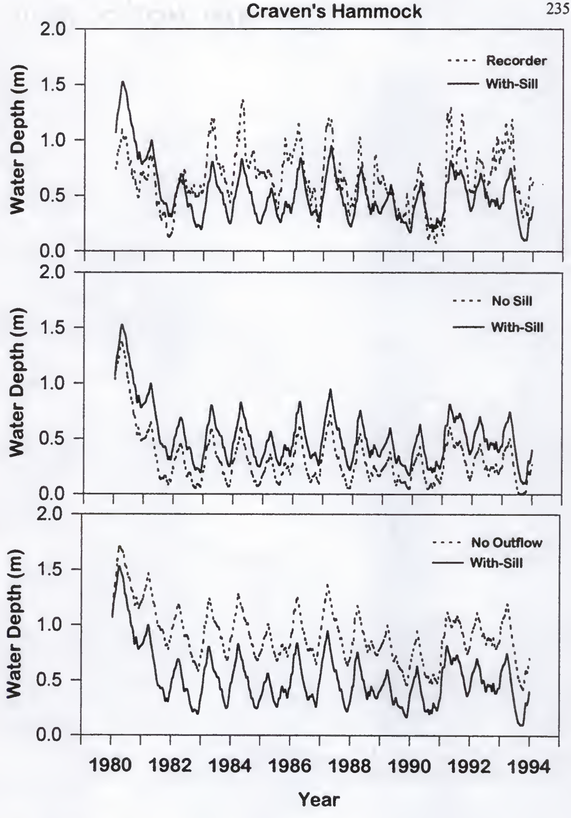

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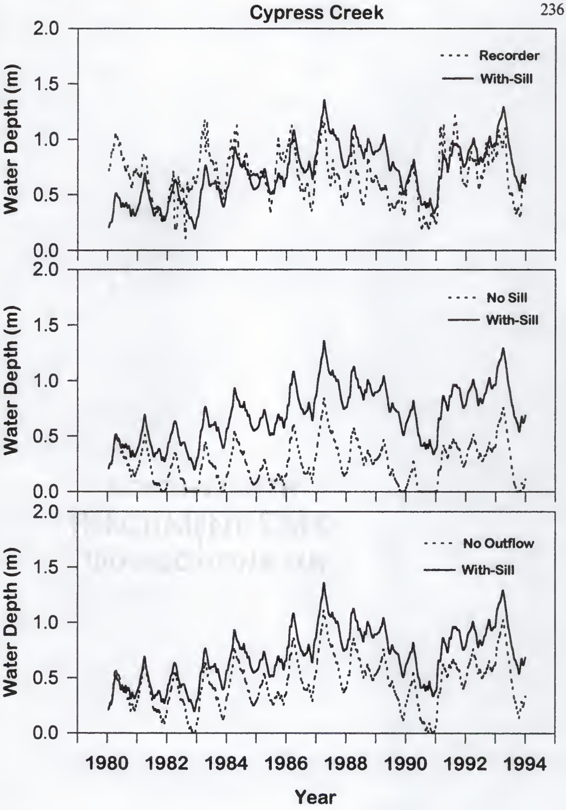

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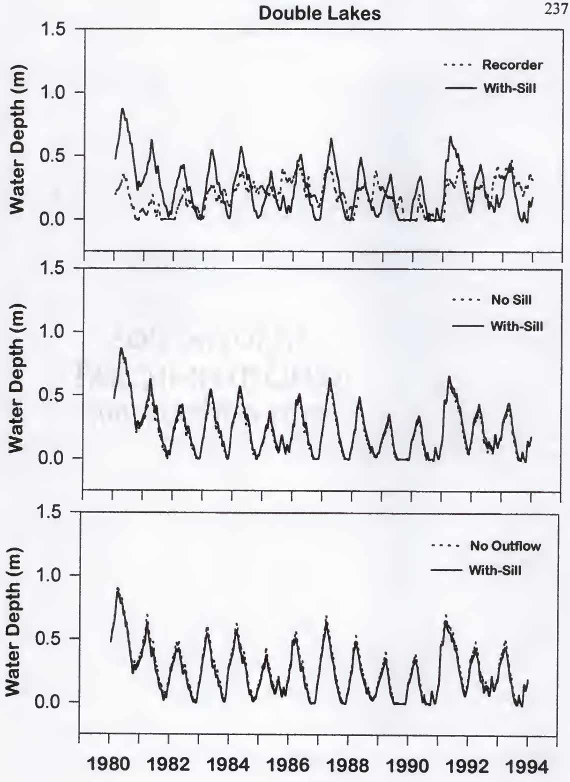

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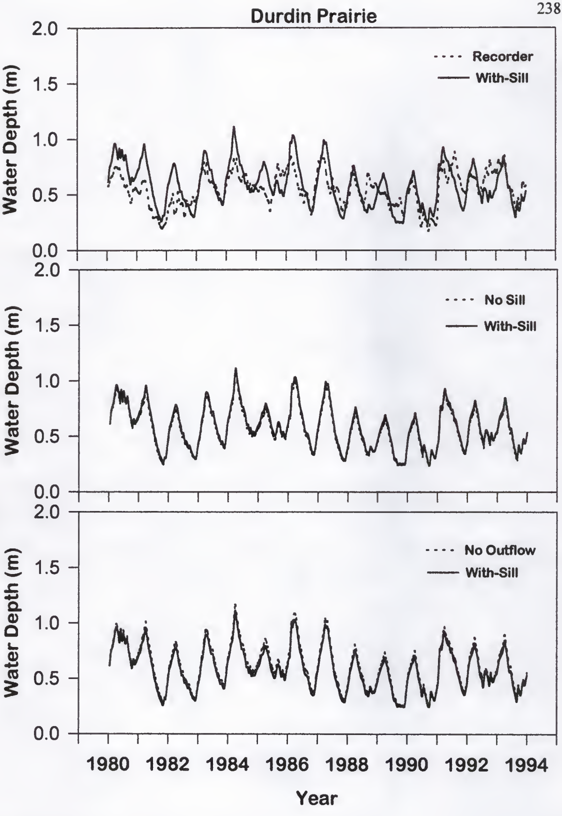

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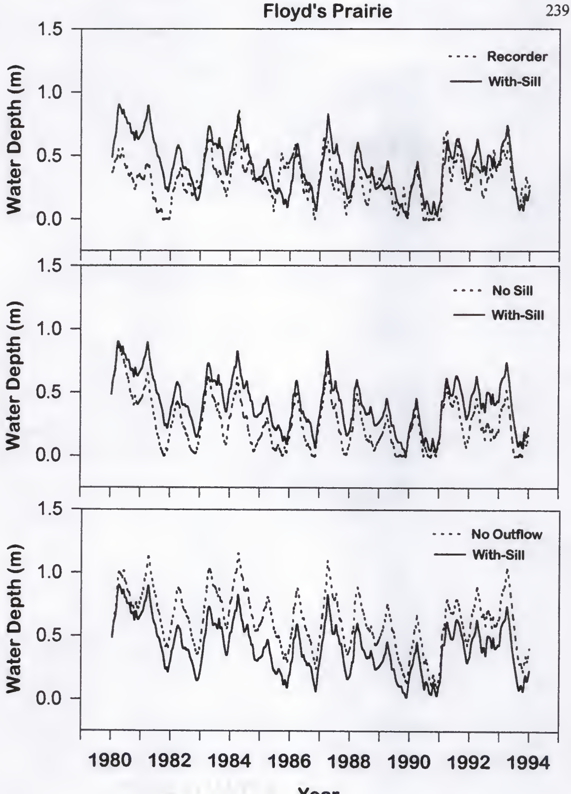

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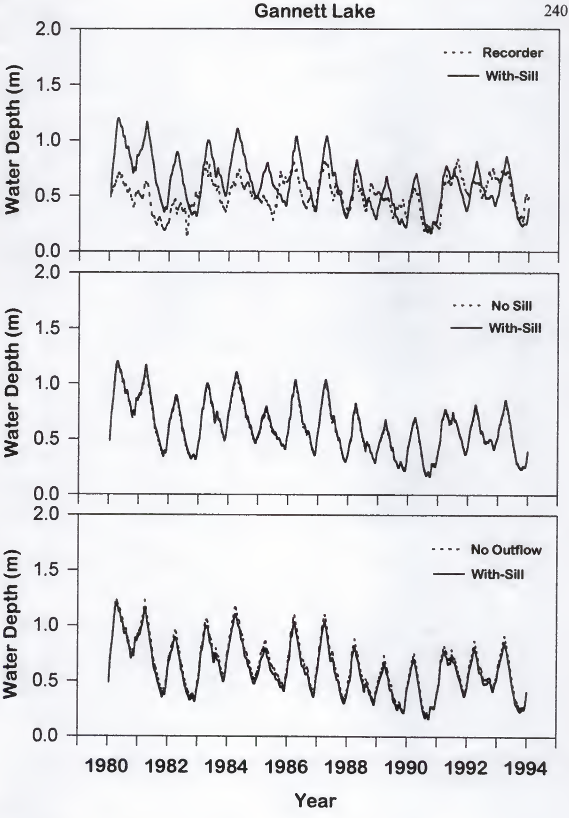

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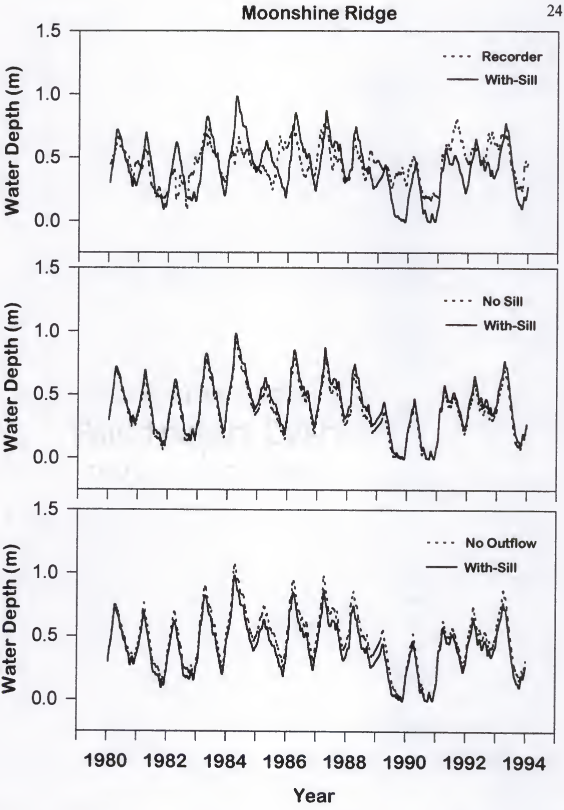

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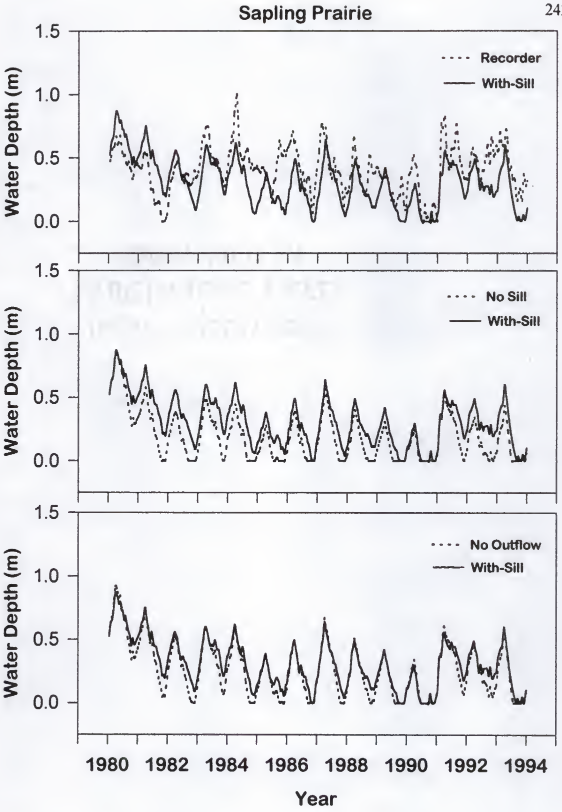

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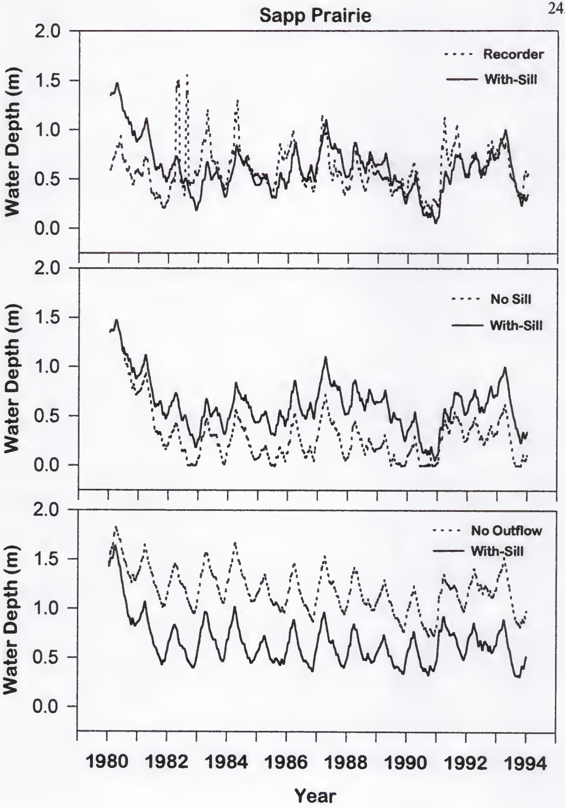

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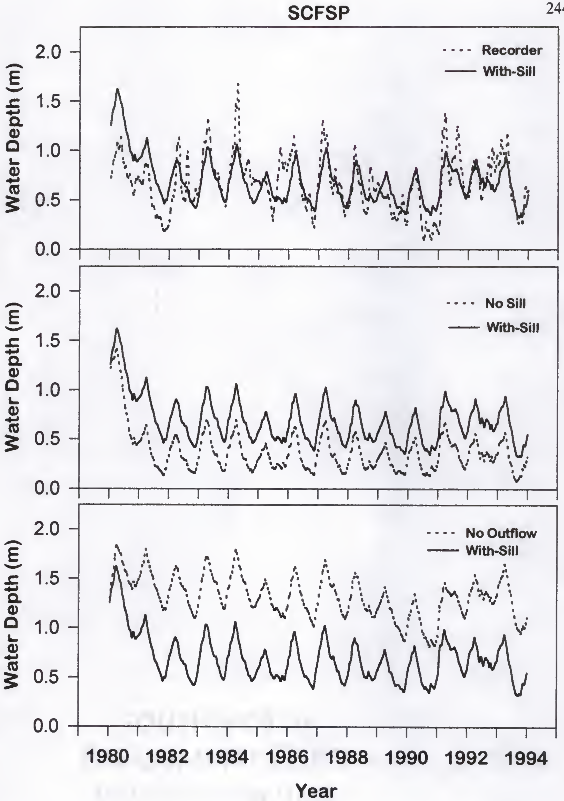

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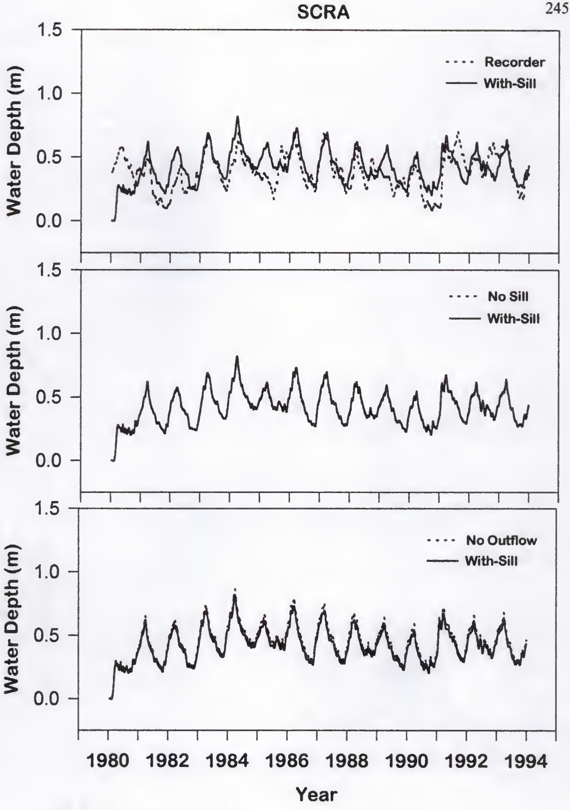

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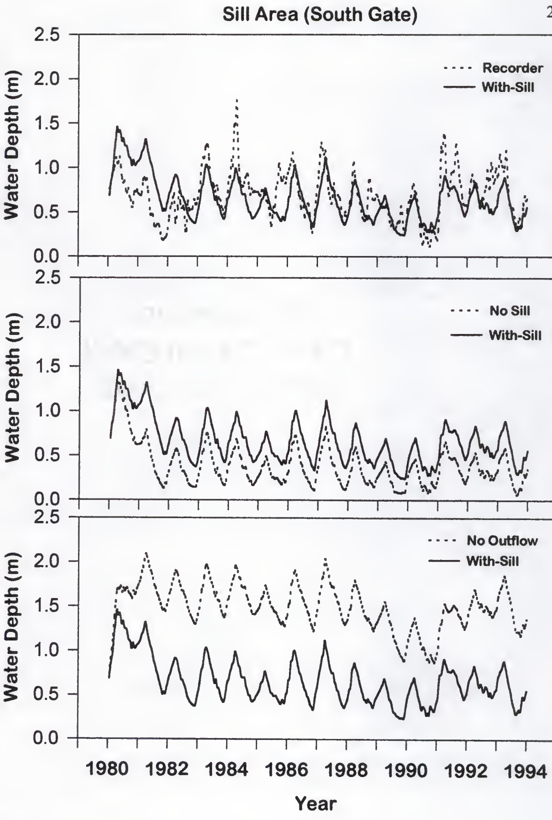

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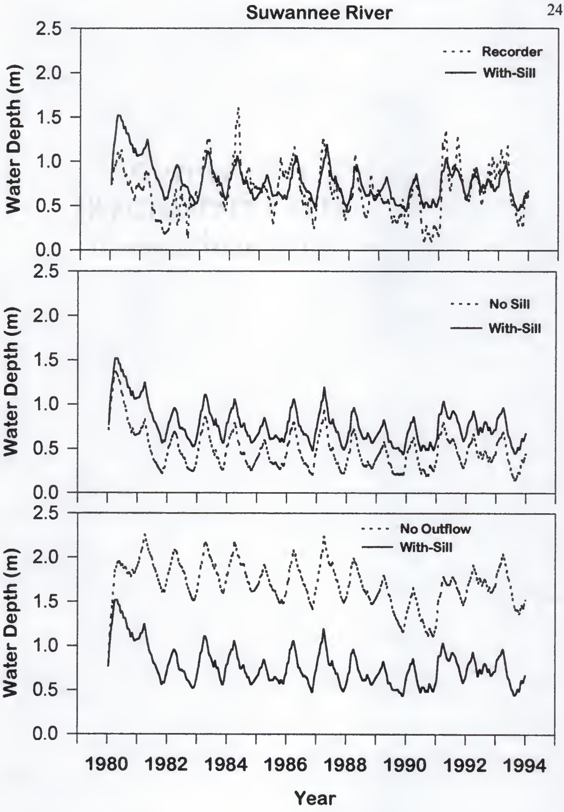

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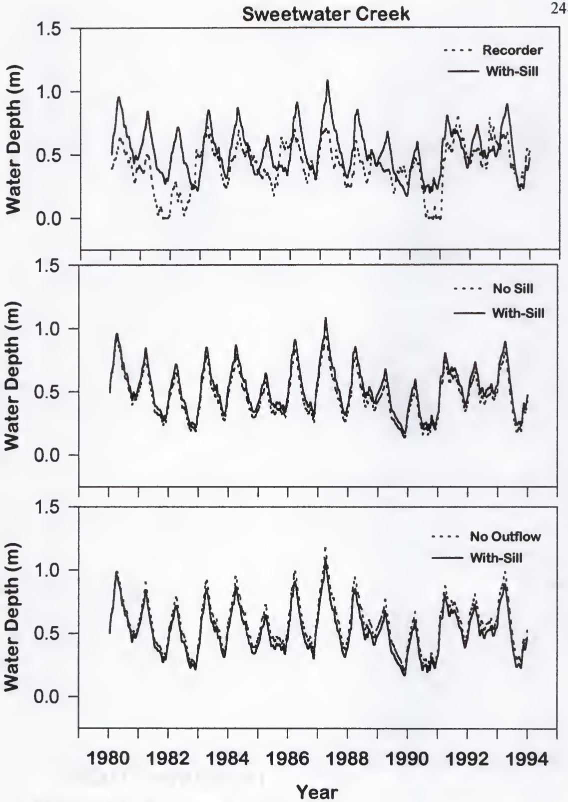

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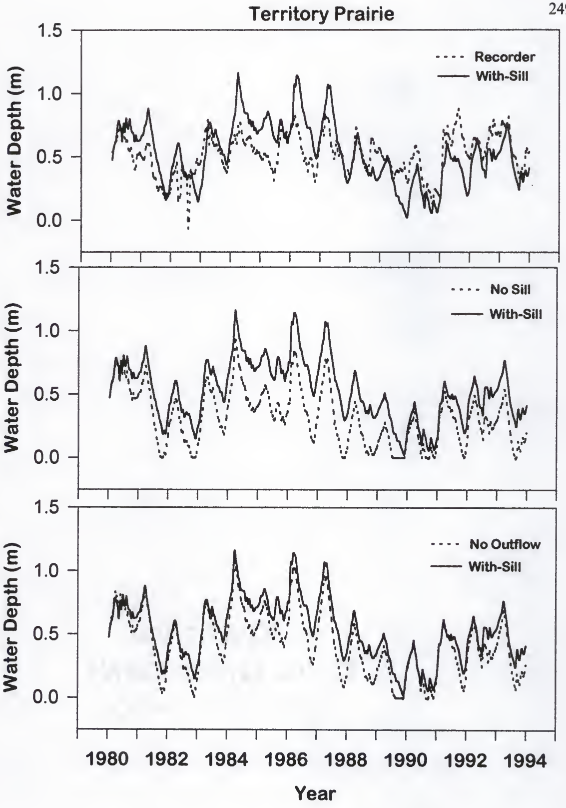

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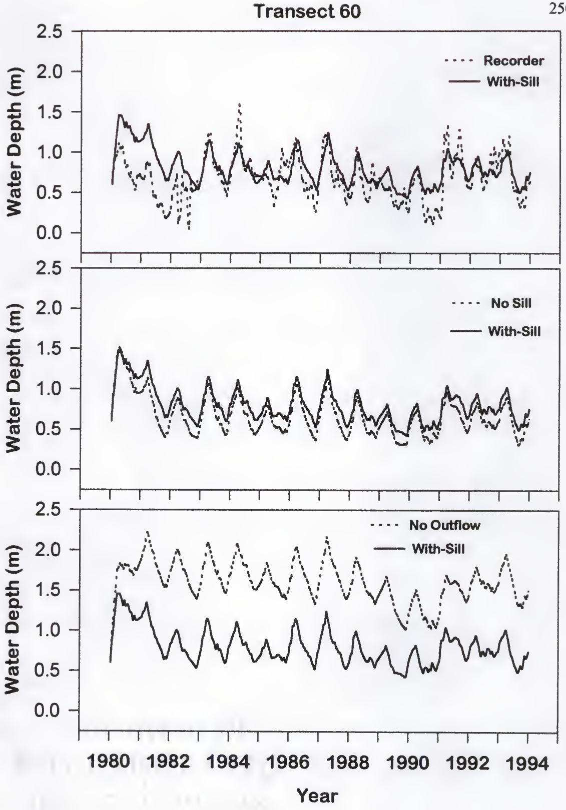

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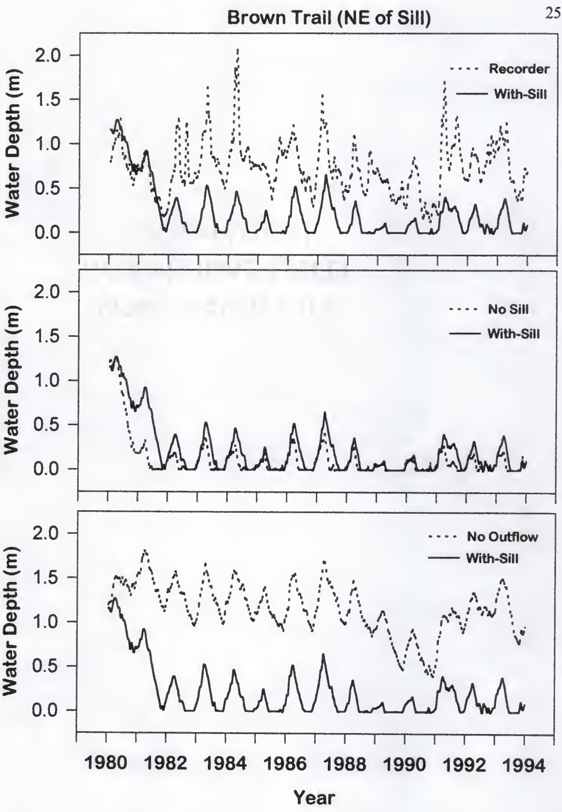
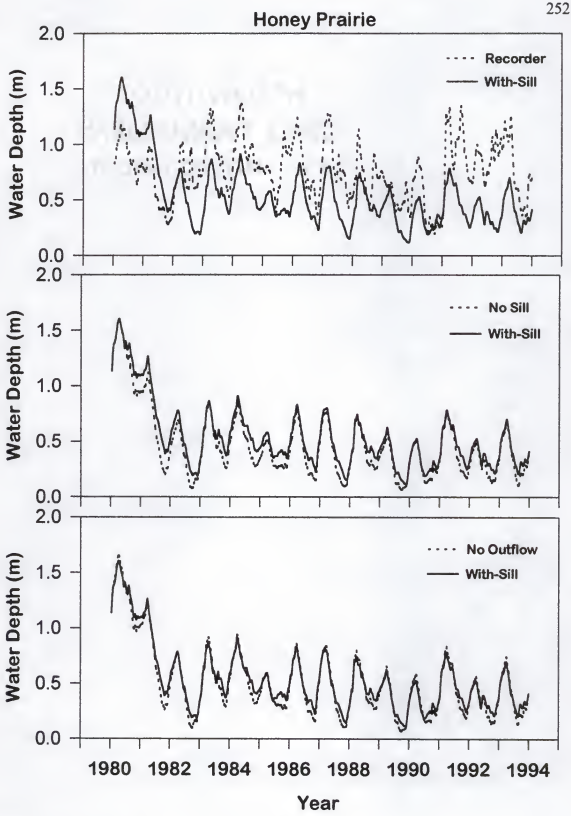


Figure 3-11. Estimated recorder data and model output from stations with poor model performance in "with-sill" and "no-sill" simulations for 1980-1993.



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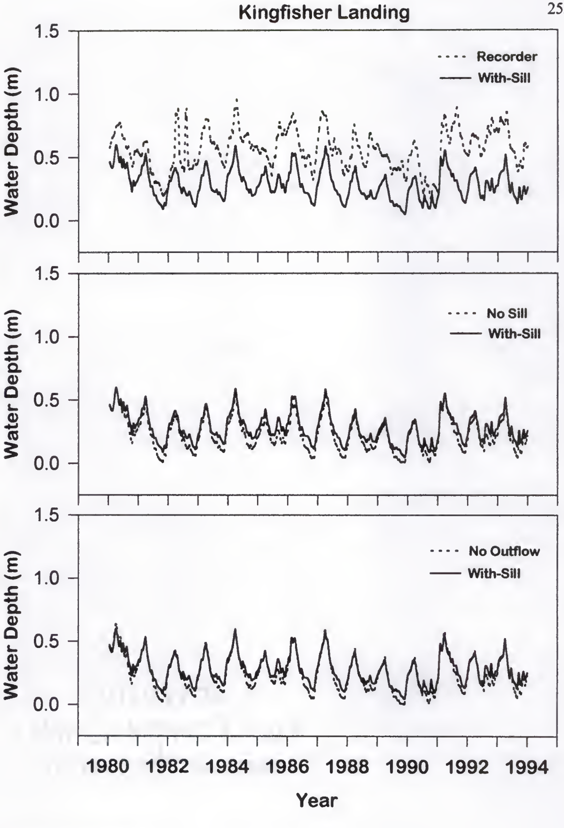

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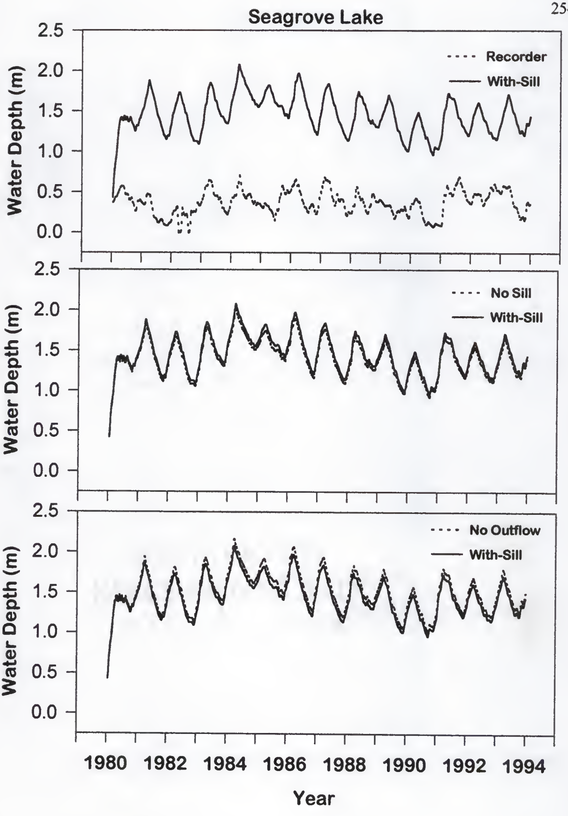

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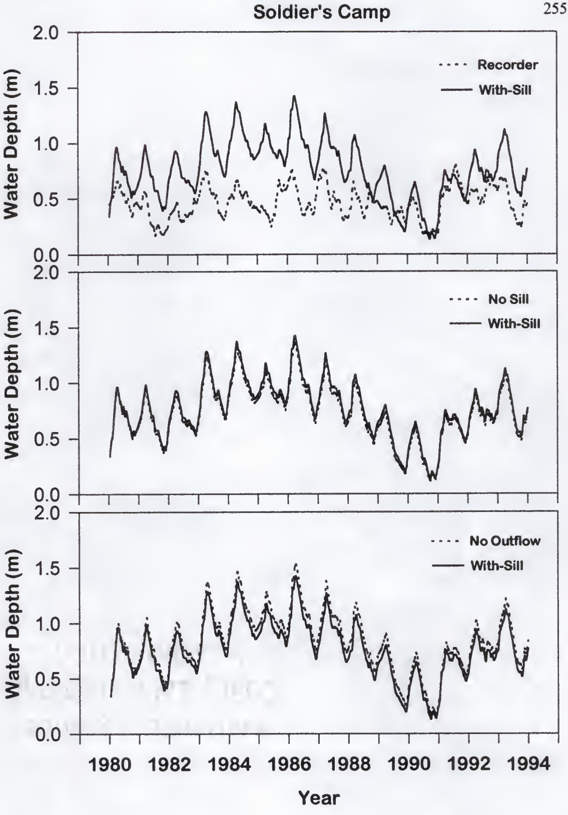

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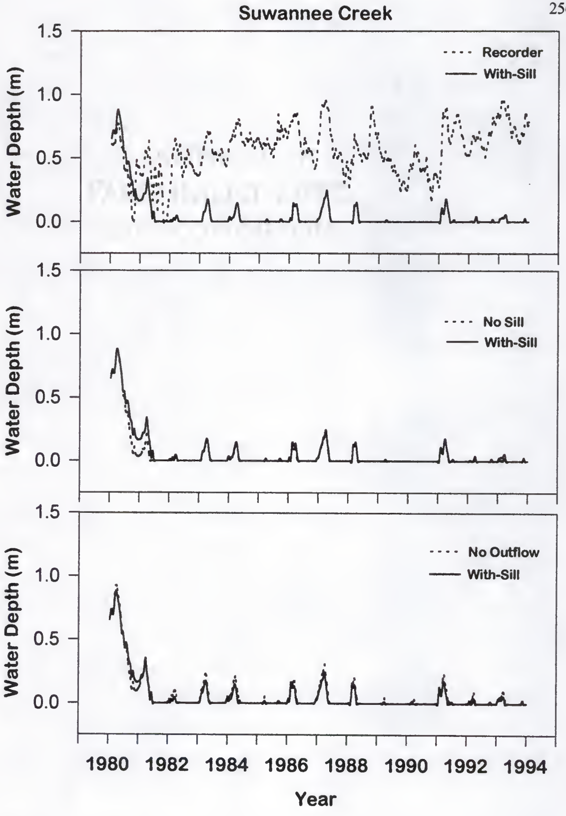

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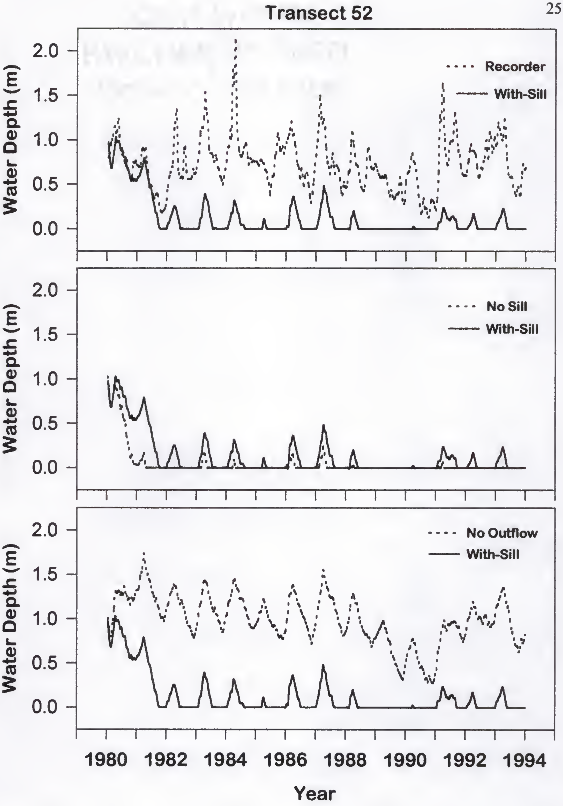

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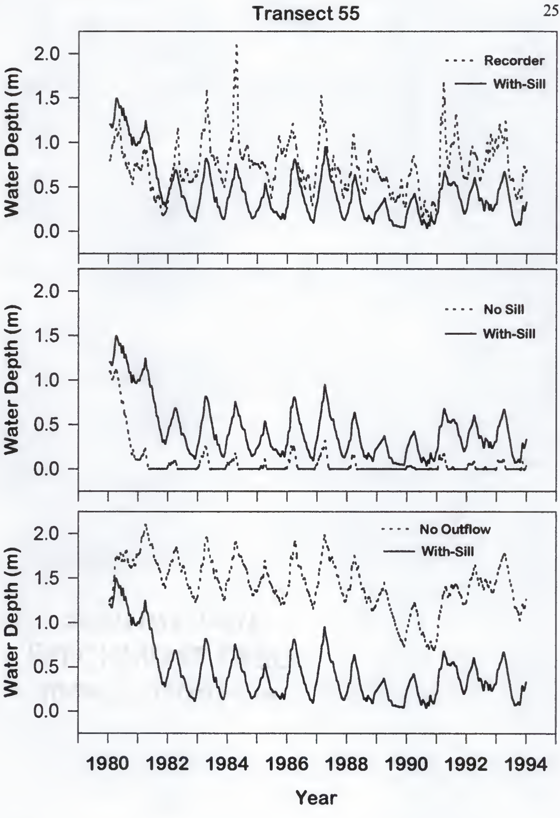


Figure 3-11--continued.

that reached the perimeter was forced back into the swamp unless in the outflow zone or in areas with topographic data beyond the refuge perimeter (South and Southwest). This probably accelerated accumulation at these sites (Seagrove Lake, Soldier's Camp). Additionally the paucity of topographic survey points along the eastern edge leading up to Trail Ridge may have contributed error to the topographic surface and subsequently to the water depth calculations (Figure 2-18). Poor agreement along the east-central perimeter may also reflect the lack of information about the hydrology of the seepage flows entering the swamp in this region. The model may have underestimated water depths at Kingfisher Landing, Chase Prairie, Sill, Honey Prairie, and Transect 52 and Transect 55 because the topographic environments at these recorder locations were atypical of the area and these features were not preserved in the water depth interpolations. This is most likely an artifact of model data scale, which was limited by computer resources. Model output was more often in agreement with water level recorder data that had been interpolated among stations using kriging and a 50m cell size, than data extracted directly from the recorders. Non-kriged data were in better agreement with model output than interpolated data where recorder locations were more representative of the area's general topography, and stations were not located in trails, canals, ditches, or holes in the peat (Table 3-2). The model appeared to suitably represent outflowing creeks and rivers using the Suwannee River outflow zone and topographic gradients, but water depth estimates at the Suwannee Creek recorder site were low. Adjustments to the inflow and outflow proportion coefficients did not improve this performance.

Table 3-2. Best HYDRO-MODEL settings and check data format for stations in Okefenokee Swamp during 1941-1993 model simulations.

Station and Interval	Evapotranspiration Coefficients[a]	Suwannee River Outflow Coefficient	Check Data Type	Model Performance[b]
1941-1949				
Billy's Lake	1.0, 1.0, 1.0	0.20	kriged	fair
Chase Prairie	1.0, 1.0, 1.0	0.20	non-kriged	fair
Chesser Prairie	1.2, 1.2, 1.2	0.30	non-kriged	high
Coffee Bay	1.2, 1.2, 1.2	0.30	kriged	fair
Craven's Hammock	1.2, 1.2, 1.2	0.30	non-kriged	fair
Cypress Creek	1.15, 1.15, 1.15	0.20	non-kriged	fair
Double Lakes	1.15, 1.15, 1.15	0.20	kriged	fair
Durdin Prairie	1.2, 1.2, 1.2	0.30	kriged	fair
Floyd's Prairie	1.15, 1.15, 1.15	0.20	non-kriged	fair
Gannett Lake	1.2, 1.2, 1.2	0.30	kriged	high
Honey Prairie	1.0, 1.0, 1.0	0.20	kriged	fair
Kingfisher Landing	1.0, 1.0, 1.0	0.20	kriged	fair
Moonshine Ridge	1.2, 1.2, 1.2	0.30	kriged	fair
Suwannee River	1.0, 1.0, 1.0	0.20	kriged	fair
Sapling Prairie	1.2, 1.2, 1.2	0.30	non-kriged	fair
Sapp Prairie	1.0, 1.0, 1.0	0.20	kriged	low
SCFSP	1.0, 1.0, 1.0	0.20	kriged	fair
SCRA	1.2, 1.2, 1.2	0.30	kriged	fair
Seagrove Lake	1.2, 1.2, 1.2	0.30	kriged	high
Brown Trail (Sill)	1.0, 1.0, 1.0	0.20	kriged	low
South Sill Gate	1.0, 1.0, 1.0	0.20	kriged	fair
Soldier's Camp	1.2, 1.2, 1.2	0.30	kriged	high

Station and Interval	Evapotranspiration Coefficients[a]	Suwannee River Outflow Coefficient	Check Data Type	Model Performance[b]
Suwannee Creek	1.0, 1.0, 1.0	0.20	non-kriged	low
Sweetwater Creek	1.0, 1.0, 1., 0	0.20	kriged	fair
Territory Prairie	1.15, 1.15, 1.15	0.20	kriged	fair
Transect 60	1.2, 1.2, 1.2	0.30	kriged	fair
1950-1959				
Billy's Lake	1.25, 1.25, 1.25	0.20	kriged	good
Chase Prairie	1.25, 1.25, 1.25	0.15	non-kriged	good
Chesser Prairie	1.25, 1.25, 1.25	0.20	non-kriged	high
Coffee Bay	1.25, 1.25, 1.25	0.20	kriged	high
Craven's Hammock	1.25, 1.25, 1.25	0.15	kriged	fair
Cypress Creek	1.25, 1.25, 1.25	0.20	non-kriged	high
Double Lakes	1.25, 1.25, 1.25	0.15	kriged	fair
Durdin Prairie	1.25, 1.25, 1.25	0.20	kriged	fair
Floyd's Prairie	1.25, 1.25, 1.25	0.20	non-kriged	good
Gannett Lake	1.25, 1.25, 1.25	0.20	kriged	high
Honey Prairie	1.25, 1.25, 1.25	0.15	kriged	good
Kingfisher Landing	1.25, 1.25, 1.25	0.15	kriged	low
Moonshine Ridge	1.25, 1.25, 1.25	0.20	kriged	fair
Suwannee River	1.25, 1.25, 1.25	0.20	kriged	fair
Sapling Prairie	1.25, 1.25, 1.25	0.15	non-kriged	fair
Sapp Prairie	1.25, 1.25, 1.25	0.15	kriged	low
SCFSP	1.25, 1.25, 1.25	0.20	kriged	fair
SCRA	1.25, 1.25, 1.25	0.20	kriged	high
Seagrove Lake	1.25, 1.25, 1.25	0.20	kriged	high
Brown Trail (Sill)	1.25, 1.25, 1.25	0.15	kriged	low

Station and Interval	Evapotranspiration Coefficients[a]	Suwannee River Outflow Coefficient	Check Data Type	Model Performance[b]
South Sill Gate	1.25, 1.25, 1.25	0.20	kriged	fair
Soldier's Camp	1.25, 1.25, 1.25	0.20	kriged	high
Suwannee Creek	1.25, 1.25, 1.25	0.15	kriged	low
Sweetwater Creek	1.25, 1.25, 1.25	0.15	kriged	fair
Territory Prairie	1.25, 1.25, 1.25	0.15	kriged	fair
Transect 60	1.25, 1.25, 1.25	0.20	kriged	high
1960-1969				
Billy's Lake	1.25, 1.25, 1.25	0.15	kriged	fair
Chase Prairie	1.25, 1.25, 1.25	0.15	non-kriged	fair
Chesser Prairie	1.25, 1.25, 1.25	0.20	non-kriged	high
Coffee Bay	1.25, 1.25, 1.25	0.20	kriged	high
Craven's Hammock	1.25, 1.25, 1.25	0.20	non-kriged	good
Cypress Creek	1.25, 1.25, 1.25	0.15	kriged	low
Double Lakes	1.25, 1.25, 1.25	0.20	non-kriged	fair
Durdin Prairie	1.25, 1.25, 1.25	0.20	kriged	good
Floyd's Prairie	1.25, 1.25, 1.25	0.15	non-kriged	good
Gannett Lake	1.25, 1.25, 1.25	0.20	kriged	high
Honey Prairie	1.25, 1.25, 1.25	0.15	kriged	low
Kingfisher Landing	1.25, 1.25, 1.25	0.15	kriged	low
Moonshine Ridge	1.25, 1.25, 1.25	0.20	kriged	fair
Suwannee River	1.25, 1.25, 1.25	0.15	kriged	good
Sapling Prairie	1.25, 1.25, 1.25	0.15	non-kriged	fair
Sapp Prairie	1.25, 1.25, 1.25	0.15	kriged	low
SCFSP	1.25, 1.25, 1.25	0.15	kriged	good
SCRA			kriged	good

Table 3-2--continued.

Station and Interval	Evapotranspiration Coefficients[a]	Suwannee River Outflow Coefficient	Check Data Type	Model Performance[b]
Seagrove Lake	1.25, 1.25, 1.25	0.20	kriged	high
Brown Trail (Sill)	1.25, 1.25, 1.25	0.15	kriged	low
South Sill Gate	1.25, 1.25, 1.25	0.15	kriged	fair
Soldier's Camp	1.25, 1.25, 1.25	0.20	kriged	high
Suwannee Creek	1.25, 1.25, 1.25	0.15	non-kriged	low
Sweetwater Creek	1.25, 1.25, 1.25	0.15	kriged	high
Territory Prairie	1.25, 1.25, 1.25	0.20	non-kriged	fair
Transect 60	1.25, 1.25, 1.25	0.15	kriged	good
1970-1979				
Billy's Lake	1.20, 1.20, 1.20	0.15	kriged	fair
Chase Prairie	1.20, 1.20, 1.20	0.15	non-kriged	good
Chesser Prairie	1.30, 1.30, 1.30	0.15	non-kriged	high
Coffee Bay	1.30, 1.30, 1.30	0.15	kriged	high
Craven's Hammock	1.25, 1.25, 1.25	0.20	non-kriged	good
Cypress Creek	1.30, 1.30, 1.30	0.15	kriged	good
Double Lakes	1.25, 1.25, 1.25	0.20	non-kriged	fair
Durdin Prairie	1.20, 1.20, 1.20	0.15	kriged	good
Floyd's Prairie	1.30, 1.30, 1.30	0.15	non-kriged	good
Gannett Lake	1.30, 1.30, 1.30	0.15	kriged	high
Honey Prairie	1.20, 1.20, 1.20	0.15	kriged	good
Kingfisher Landing	1.20, 1.20, 1.20	0.15	kriged	low
Moonshine Ridge	1.30, 1.30, 1.30	0.15	kriged	fair
Suwannee River	1.20, 1.20, 1.20	0.15	kriged	good
Sapling Prairie	1.20, 1.20, 1.20	0.15	non-kriged	good
Sapp Prairie	1.20, 1.20, 1.20	0.15	kriged	high

Station and Interval	Evapotranspiration Coefficients[a]	Suwannee River Outflow Coefficient	Check Data Type	Model Performance[b]
SCFSP	1.20, 1.20, 1.20	0.15	kriged	fair
SCRA	1.30, 1.30, 1.30	0.15	kriged	fair
Seagrove Lake	1.30, 1.30, 1.30	0.15	kriged	high
Brown Trail (Sill)	1.20, 1.20, 1.20	0.15	kriged	low
South Sill Gate	1.20, 1.20, 1.20	0.15	kriged	fair
Soldier's Camp	1.30, 1.30, 1.30	0.15	kriged	high
Suwannee Creek	1.20, 1.20, 1.20	0.15	non-mkriged	low
Sweetwater Creek	1.25, 1.25, 1.25	0.20	kriged	good
Territory Prairie	1.30, 1.30, 1.30	0.15	non-kriged	fair
Transect 60	1.25, 1.25, 1.25	0.20	kriged	good
1980-1993				
Billy's Lake	1.25, 1.25, 1.25	0.10	kriged	good
Chase Prairie	1.25, 1.00, 1.00	0.15	non-kriged	fair
Chesser Prairie	1.25, 1.25, 1.25	0.10	non-kriged	good
Coffee Bay	1.25, 1.25, 1.25	0.10	kriged	good
Craven's Hammock	1.25, 1.25, 1.25	0.10	kriged	good
Cypress Creek	1.25, 1.00, 1.00	0.15	kriged	good
Double Lakes	1.25, 1.25, 1.25	0.10	non-kriged	good
Durdin Prairie	1.25, 1.25, 1.25	0.10	kriged	good
Floyd's Prairie	1.25, 1.00, 1.00	0.15	non-kriged	good
Gannett Lake	1.25, 1.25, 1.25	0.10	kriged	good
Honey Prairie	1.25, 1.00, 1.00	0.15	kriged	low
Kingfisher Landing	1.25, 1.00, 1.00	0.15	kriged	low
Moonshine Ridge	1.25, 1.25, 1.25	0.10	kriged	good

Station and Interval	Evapotranspiration Coefficients[a]	Suwannee River Outflow Coefficient	Check Data Type	Model Performance[b]
Suwannee River	1.25, 1.00, 1.00	0.15	kriged	good
Sapling Prairie	1.25, 1.00, 1.00	0.15	non-kriged	fair
Sapp Prairie	1.25, 1.00, 1.00	0.15	kriged	good
SCFSP	1.25, 1.25, 1.25	0.10	kriged	good
SCRA	1.25, 1.25, 1.25	0.10	kriged	good
Seagrove Lake	1.25, 1.25, 1.25	0.10	kriged	high
Brown Trail (Sill)	1.25, 1.25, 1.25	0.10	kriged	low
South Sill Gate	1.25, 1.25, 1.25	0.10	kriged	good
Soldier's Camp	1.25, 1.25, 1.25	0.10	kriged	high
Suwannee Creek	1.25, 1.00, 1.00	0.15	non-kriged	low
Sweetwater Creek	1.25, 1.25, 1.25	0.10	non-kriged	good
Territory Prairie	1.25, 1.00, 1.00	0.15	kriged	good
Transect 60	1.25, 1.00, 1.00	0.15	kriged	good

[a] Evapotranspiration coefficients for 4 seasons: April-May and October-November, June-September, December-March.
[b] Model performance was assessed by visual inspection of agreement between hydrographs of model output and check station recorder data. See Figures 3-9 and 3-10 for model and recorder data plots.

A single model did not adequately represent the hydrologic environment of the entire swamp during 1980-1993. Various settings of the model parameters were tried, and the best agreement with recorder data was achieved with 2 versions of the model. The swamp basins discussed in Chapter 2 correspond to the areas affected by the different models. The variability in model performance reflects the spatial variability of the swamp hydrologic environment; spatial overlap in the model reponses is also attributed to model processing scale.

Five stations in the swamp's western basin (Floyd's Prairie, Suwannee River, Sapling Prairie, Transect 60, Cypress Creek) demonstrated better agreement with model settings providing more surface outflow in the Suwannee River outflow zone (setting=0.15) and less ET (settings=1.25, 1.0, 1.0); agreement with recorder data at 3 stations in the central (Chase Prairie, Territory Prairie) and southwest (Sapp Prairie) basins was also best with these settings. An alternative model (ET=1.25, 1.25, 1.25; outflow zone=0.10) with lower outflow volumes and higher evapotranspiration volumes agreed with model data at 4 stations in the swamp western basin (Billys Lake, SCFSP, Sill Gate, Cravens Hammock, Sweetwater Creek), 2 stations in the northeastern basin (Double Lakes, Durdin Prairie), 1 station in the southeastern basin (Moonshine Ridge), and 4 stations in the central basin (Chesser Prairie, Coffee Bay, Gannett Lake, SCRA).

The model reflects the periodicity of water level fluctuations at all of the recorder check stations, with cycles of high and low water depths mirroring seasonal fluctuations in evapotranspiration. Amplitudes of these fluctuations are less accurate, with model output in western and southwestern areas less variable than recorder data, and model

output in eastern, central, and southeastern areas slightly more variable than recorder data. Amplitudes were most accurate at Floyd's Prairie, Sill Gate, Transect 60, Coffee Bay, SCRA, and Territory Prairie. Greatest water level fluctuations during 1980-1993 were recorded in the Suwannee River floodplain (Billy's Lake, SCFSP, Suwannee River, Craven's Hammock, Sill Gate, Transect 60), where model error ranged 1-11% of total station variability. Water level fluctuations were least in prairie, lake, and canal areas (Chase Prairie, Double Lakes, Durdin Prairie, Gannett Lake, Moonshine Ridge, SCRA), with model error ranging 5-16% of total station variability. Model error was proportional to a site's overall data water depth range; model error was $<15\%$ of the recorded range in water depth at 17 of the 21 check stations, and $\leq 10\%$ at 13 of the 21 check stations (Table 3-3). Therefore, model performance was generally sufficient to indicate affects of the sill.

Model Responses to Sill Manipulations

To approximate the hydrologic environment that might have occurred had the sill been absent during 1980-1993, the model was modified to use the pre-sill topographic surface. The flow rate in the Suwannee River was set to 0.20, similar to that used in the "no-sill" model runs of 1941-1959, and evapotranspiration rates (1.25, 1.25, 1.25) were similar to those in the 1980-1993 "with-sill" model runs. Biweekly changes in water depths at creek stations are illustrated in Figure 3-10, and differences from "with-sill" averages are listed in Table 3-4. Greatest changes in water depths were measured at Cypress Creek, SCFSP, Billy's Lake, Sapp Prairie, Suwannee River, and the Sill Gate

Table 3-3. Comparison of check station data and best model output, 1980-1993.

Station	Check Station Estimated Average Water Depth (m)	Best Model Estimated Average Water Depth (m)	Recorder Water Depth Range (m)	Model-Check Station/ Check Station Range (%)	Error[a] = 0 cm	Error >0 and ≤10 cm	Error >10 and ≤ 20 cm	Error >20 and ≤ 30 cm	Error >30 and ≤40 cm	Error >40 and ≤ 50 cm	Error >50 and ≤ 60 cm	Error >60 and ≤70 cm	Error >70 and ≤100 cm
Billy's Lake	0.68	0.66	1.63	-1	0	1	8	61	27	3	0	0	0
Chase Prairie	0.27	0.20	0.48	-14	0	55	39	0	0	0	0	0	0
Chesser Prairie	0.89	1.02	0.71	12	0	100	0	0	0	0	0	0	0
Coffee Bay	0.52	0.66	0.92	16	0	100	0	0	0	0	0	0	0
Craven's Hammock	0.66	0.52	1.29	-11	0	2	40	53	5	0	0	0	0
Cypress Creek	0.67	0.70	1.03	3	0	4	7	7	12	23	39	8	0
Double Lakes	0.20	0.24	0.47	10	2	90	0	0	0	0	0	0	0
Durdin Prairie	0.55	0.59	0.71	5	0	100	0	0	0	0	0	0	0
Floyd's Prairie	0.31	0.42	0.86	13	0	27	38	62	3	0	0	0	0

Table 3-3--continued.

Station	Check Station Estimated Average Water Depth (m)	Best Model Estimated Average Water Depth (m)	Recorder Water Depth Range (m)	Model-Check Station/ Check Station Range (%)	Error[a] = 0 cm	Error >0 and ≤10 cm	Error >10 and ≤ 20 cm	Error >20 and ≤ 30 cm	Error >30 and ≤ 40 cm	Error >40 and ≤ 50 cm	Error >50 and ≤ 60 cm	Error >60 and ≤70 cm	Error >70 and ≤100 cm
Gannett Lake	0.51	0.61	0.68	16	14	85	0	0	0	0	0	0	0
Moonshine Ridge	0.46	0.42	0.69	-5	0	98	0	0	0	0	0	0	0
Suwannee River	0.68	0.77	1.50	7	0	1	2	65	25	7	0	0	0
Sapling Prairie	0.41	0.31	1.00	-10	0	33	51	11	0	0	0	0	0
Sapp Prairie	0.60	0.62	1.25	1	0	5	16	22	36	19	0	0	0
SCFSP	0.67	0.69	1.58	1	0	1	1	37	53	8	0	0	0
SCRA	0.39	0.42	0.65	5	19	75	0	0	0	0	0	0	0
South Sill Gate	0.70	0.66	1.65	-2	1	1	9	58	24	3	4	0	0
Soldier's Camp	0.46	0.77	0.64	48	0	100	0	0	0	0	0	0	0
Sweetwater Creek	0.41	0.53	0.79	15	0	100	0	0	0	0	0	0	0

Table 3-3--continued.

Station	Check Station Estimated Average Water Depth (m)	Best Model Estimated Average Water Depth (m)	Recorder Water Depth Range (m)	Model-Check Station/ Check Station Range (%)	Error[a] = 0 cm	Error >0 and ≤10 cm	Error >10 and ≤ 20 cm	Error >20 and ≤ 30 cm	Error >30 and ≤ 40 cm	Error >40 and ≤ 50 cm	Error >50 and ≤ 60 cm	Error >60 and ≤70 cm	Error >70 and ≤100 cm
Territory Prairie	0.52	0.53	0.87	2	0	15	26	40	19	0	0	0	0
Transect 60	0.68	0.81	1.48	9	3	19	67	11	0	0	0	0	0

[a] % of biweekly intervals (n=336) in 1980-1993 with difference between modeled and recorded/estimated with-sill water depths by 10 cm increments.

Table 3-4. Summary statistics of recorder data and model output at check stations during 1980-1993.

Station (n=336 biweekly intervals)	Condition	Mean Water Depth (m)	Standard Deviation	Minimum	Maximum
Billy's Lake	With sill	0.66	0.23	0.32	1.64
	No sill	0.38	0.22	0.10	1.45
	No outflow	1.19	0.21	0.72	1.83
	Recorder	0.68	0.28	0.10	1.73
Chase Prairie	With sill	0.20	0.14	0.00	0.63
	No sill	0.12	0.13	0.00	0.59
	No outflow	0.21	0.16	0.00	0.66
	Recorder	0.27	0.11	0.00	0.48
Chesser Prairie	With sill	1.02	0.23	0.48	1.63
	No sill	0.97	0.23	0.44	1.55
	No outflow	1.10	0.24	0.54	1.72
	Recorder	0.89	0.22	0.21	1.36
Coffee Bay	With sill	0.66	0.19	0.24	1.18
	No sill	0.62	0.18	0.22	1.10
	No outflow	0.74	0.20	0.28	1.29
	Recorder	0.52	0.18	0.01	0.92
Craven's Hammock	With sill	0.52	0.25	0.10	1.52
	No sill	0.32	0.24	0.00	1.37
	No outflow	0.92	0.24	0.42	1.71
	Recorder	0.66	0.26	0.08	1.36
Cypress Creek	With sill	0.70	0.24	0.20	1.36
	No sill	0.26	0.18	0.00	0.84
	No outflow	0.45	0.22	0.00	1.11
	Recorder	0.67	0.23	0.18	1.22
Double Lakes	With sill	0.24	0.19	0.00	0.86
	No sill	0.22	0.18	0.00	0.84
	No outflow	0.27	0.20	0.00	0.89
	Recorder	0.20	0.12	0.00	0.47

Station (n=336 biweekly intervals)	Condition	Mean Water Depth (m)	Standard Deviation	Minimum	Maximum
Durdin Prairie	With sill	0.59	0.19	0.25	1.11
	No sill	0.56	0.18	0.24	1.07
	No outflow	0.62	0.20	0.25	1.17
	Recorder	0.55	0.15	0.17	0.89
Floyd's Prairie	With sill	0.42	0.20	0.03	0.90
	No sill	0.26	0.20	0.00	0.87
	No outflow	0.63	0.22	0.10	1.15
	Recorder	0.31	0.16	0.00	0.86
Gannett Lake	With sill	0.61	0.23	0.17	1.20
	No sill	0.60	0.22	0.18	1.17
	No outflow	0.66	0.23	0.18	1.23
	Recorder	0.51	0.15	0.16	0.83
Honey Prairie	With sill	0.54	0.30	0.12	1.60
	No sill	0.47	0.30	0.07	1.59
	No outflow	0.52	0.32	0.07	1.65
	Recorder	0.77	0.26	0.20	1.37
Kingfisher Landing	With sill	0.28	0.12	0.05	0.60
	No sill	0.23	0.13	0.01	0.59
	No outflow	0.25	0.14	0.01	0.64
	Recorder	0.56	0.16	0.17	0.95
Moonshine Ridge	With sill	0.42	0.21	0.00	0.98
	No sill	0.38	0.19	0.00	0.92
	No outflow	0.49	0.22	0.00	1.07
	Recorder	0.46	0.14	0.11	0.80
Suwannee River	With sill	0.77	0.21	0.44	1.52
	No sill	0.49	0.22	0.15	1.37
	No outflow	1.71	0.24	0.83	2.26
	Recorder	0.68	0.27	0.10	1.60
Sapling Prairie	With sill	0.31	0.19	0.00	0.87
	No sill	0.19	0.19	0.00	0.85
	No outflow	0.26	0.21	0.00	0.92
	Recorder	0.41	0.18	0.00	1.00

Table 3-4--continued.

Station (n=336 biweekly intervals)	Condition	Mean Water Depth (m)	Standard Deviation	Minimum	Maximum
Sapp Prairie	With sill	0.62	0.26	0.06	1.47
	No sill	0.32	0.29	0.00	1.47
	No outflow	0.44	0.30	0.00	1.52
	Recorder	0.60	0.22	0.20	1.45
SCFSP	With sill	0.69	0.23	0.33	1.62
	No sill	0.38	0.22	0.08	1.41
	No outflow	1.33	0.21	0.82	1.83
	Recorder	0.67	0.27	0.10	1.68
SCRA	With sill	0.42	0.13	0.00	0.82
	No sill	0.41	0.13	0.00	0.80
	No outflow	0.45	0.14	0.00	0.87
	Recorder	0.39	0.14	0.08	0.74
Seagrove Lake	With sill	1.45	0.24	0.43	2.08
	No sill	1.40	0.23	0.43	2.01
	No outflow	1.52	0.25	0.44	2.16
	Recorder	0.37	0.15	0.01	0.70
Brown Trail (Sill)	With sill	0.21	0.29	0.00	1.27
	No sill	0.12	0.22	0.00	1.27
	No outflow	1.17	0.28	0.40	1.81
	Recorder	0.74	0.30	0.13	2.07
Sill Gate (South)	With sill	0.66	0.25	0.24	1.46
	No sill	0.38	0.23	0.07	1.32
	No outflow	1.50	0.25	0.73	2.09
	Recorder	0.70	0.27	0.11	1.77
Soldier's Camp	With sill	0.77	0.26	0.14	1.42
	No sill	0.73	0.25	0.12	1.36
	No outflow	0.84	0.27	0.17	1.53
	Recorder	0.46	0.14	0.17	0.80
Suwannee Creek	With sill	0.06	0.15	0.00	0.88
	No sill	0.05	0.14	0.00	0.87
	No outflow	0.06	0.15	0.00	0.93
	Recorder	0.56	0.19	0.00	0.95

Station (n=336 biweekly intervals)	Condition	Mean Water Depth (m)	Standard Deviation	Minimum	Maximum
Sweetwater Creek	With sill	0.53	0.18	0.18	1.08
	No sill	0.47	0.17	0.14	0.99
	No outflow	0.59	0.19	0.22	1.17
	Recorder	0.41	0.18	0.00	0.79
Territory Prairie	With sill	0.53	0.24	0.03	1.16
	No sill	0.32	0.22	0.00	0.93
	No outflow	0.43	0.25	0.00	1.09
	Recorder	0.52	0.16	0.01	0.88
Transect 52	With sill	0.13	0.23	0.00	1.03
	No sill	0.05	0.16	0.00	1.03
	No outflow	1.00	0.28	0.27	1.74
	Recorder	0.74	0.29	0.13	2.13
Transect 55	With sill	0.44	0.31	0.04	1.48
	No sill	0.08	0.20	0.00	1.11
	No outflow	1.44	0.28	0.69	2.10
	Recorder	0.74	0.29	0.13	2.09
Transect 60	With sill	0.81	0.21	0.44	1.46
	No sill	0.67	0.24	0.32	1.51
	No outflow	1.61	0.25	0.66	2.22
	Recorder	0.68	0.27	0.11	1.59

(Figure 3-12). Although the changes in the Suwannee River floodplain are easily attributed to the absence of the sill from the topographic surface, the changes at Cypress Creek and Sapp Prairie are puzzling. The hydrologic connectivity that exists between these stations and the sill area is outside of the refuge perimeter, in the Cypress Creek and Suwannee River drainages, and not within the swamp. Water level fluctuations in these areas are significantly correlated with those in the sill region during low and average water level conditions regardless of the sill's presence, although this relationship is weak. During high water conditions when the sill is present, water depths in the Cypress Creek basin decline and then increase with depths in the sill gate area, while Sapp Prairie water depths remain positively correlated with increasing water depths at the sill (Figure 3-13). This means that in high water conditions, levels at Cypress Creek decrease while those at the sill and Sapp Prairie are increasing. Drainage from the Cypress Creek area may be affected by variations in the hydraulic head at the creek-river junction created by the sill's impoundment of the Suwannee River. The hydraulic head must shift as more water is impounded at the sill, increasing the creek-river water surface elevation difference at the junction as more water flows freely from the creek and therefore from Sapp Prairie. As water levels decrease in both areas this difference may become smaller, decreasing drainage of the Cypress Creek area (Figure 3-14). The hydrologic environment of both areas at high water behaves independent of the sill gate area when the sill is removed from the topographic surface. Without the sill in place, the hydraulic head between the creek and river may be reduced, creating conditions for slower de-watering of the creek basin. More water is retained in the creek and at the

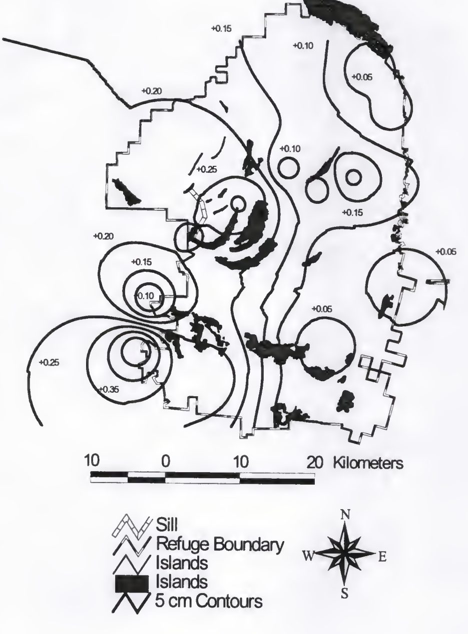


Figure 3-12. Inverse-distance-weighted, contoured estimates of increases in average semi-monthly water surface elevations (m) at recording stations, attributed to the Suwannee River sill during 1980-1993.

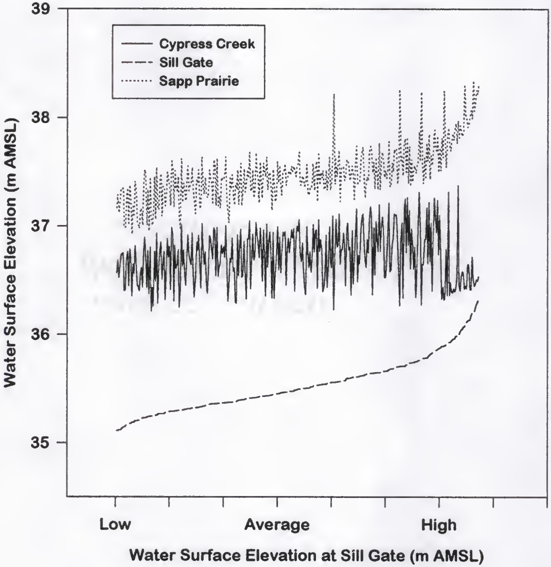


Figure 3-13. Comparison of semi-monthly water surface elevations at Cypress Creek and Sapp Prairie under increasing water level conditions in the sill gate area during 1980-1993.

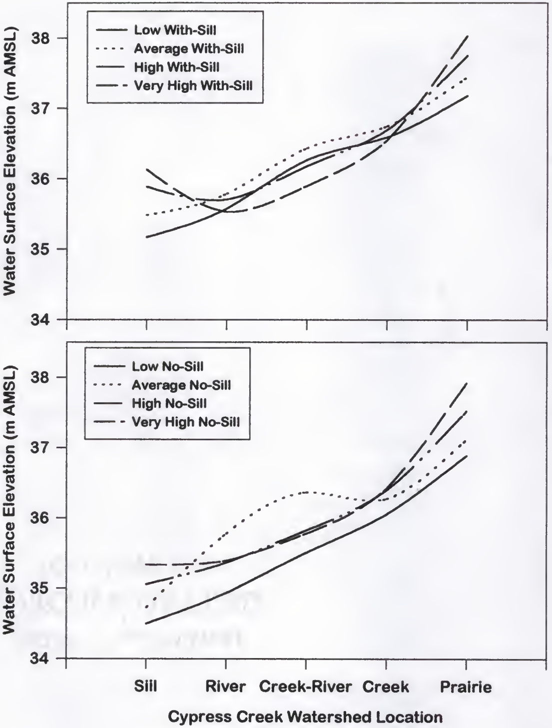


Figure 3-14. Comparison of average, semi-monthly water surface elevations in the Cypress Creek watershed under low, average, high, and very high water levels in the sill gate area during 1980-1993.

creek-river junction as it leaves the swamp, allowing a backup of water into the creek with additional precipitation (Figure 3-15) Sapp Prairie does not show this inverse relationship under high water conditions, indicating that this area is not affected by accumulating backwater causing the head reversal in the Cypress Creek and river basins. The Sweetwater Creek drainage basin is similarly affected by increased water volume with sill removal. However, like Sapp Prairie, the Suwannee River backwater effect is diluted before it reaches the creek (Figure 3-16). Water levels at these stations may also be affected by activities in the adjacent perimeter areas under timber production (such as increased surface runoff into the Suwannee River and area creeks due to clear cutting and ditching), which may also be impacting the region's drainage patterns independent of water levels in the sill impoundment.

Changes in water depths do not necessarily mean changes in duration of inundation (hydroperiod). To determine if water depth increases were accompanied by longer periods of inundation, water depths were partitioned into 7 groups (Table 3-5; see Chapter 6 for discussion of interval choice), and number of intervals in each depth group during 1980-1993 were tallied and compared between "with-sill" and "no-sill" model runs with contingency tables (G-statistic). All areas with significant changes in hydroperiod group frequencies also had some increase in average water depth with the sill in place (Table 3-6). Not all areas with water depth increases also experienced significant changes in frequencies of hydroperiod groups, however. Chesser Prairie, Coffee Bay, Double Lakes, Durdin Prairie, Gannett Lake, Moonshine Ridge, and SCRA areas increased average water depths 0.01-0.05 m without significant changes in

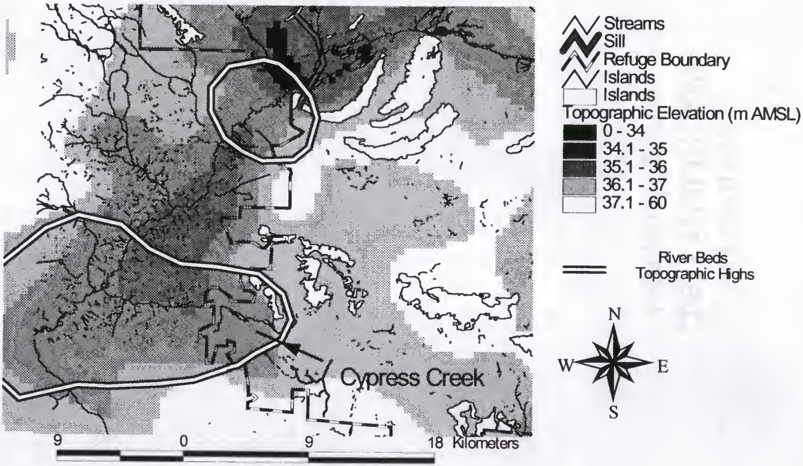


Figure 3-15. Locations of topographic highs in the Suwannee River floodplain near the Suwannee River sill and Cypress Creek.

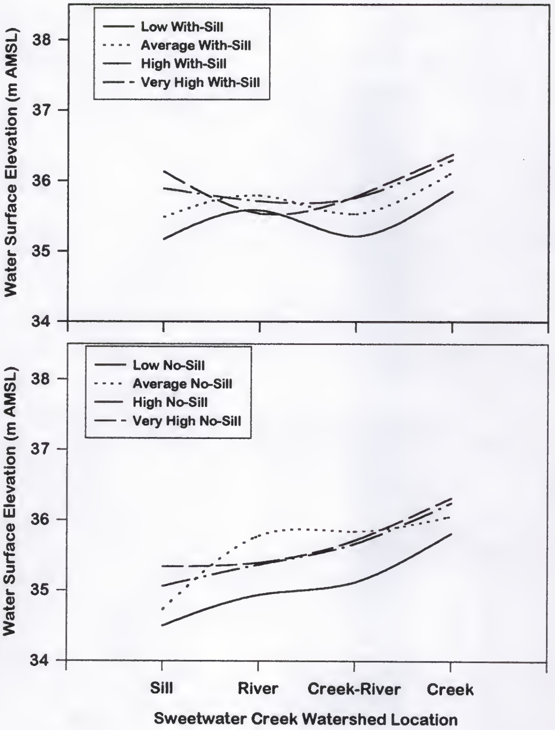


Figure 3-16. Comparison of average, semi-monthly water surface elevations in the Sweetwater Creek watershed under low, average, high, and very high water levels in the sill gate area during 1980-1993.

Table 3-5. Water depth ranges for hydroperiod group delineations.

Hydroperiod Group	Water Depth Range (m)
1	≤ 0.00 m
2	$0.00 <$ depth ≤ 0.05 m
3	$0.05 <$ depth ≤ 0.15 m
4	$0.15 <$ depth ≤ 0.30 m
5	$0.30 <$ depth ≤ 0.60 m
6	$0.60 <$ depth ≤ 1.00 m
7	depth > 1.00 m

Table 3-6. Comparisons of changes in water depths and hydroperiod group frequencies in with-sill and no-sill model simulations, 1941-1993. Stations with poor with-sill model versus recorder agreement in 1980-1993 are omitted.

Station	Interval and Sample Size	Mean Water Depth Change (With sill- No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
Billy's Lake	1941-1949 n=216	-0.16	0.05	yes	5	5, 6	4, 5	4, 5	4, 5	5	4, 5
	1950-1959 n=240	-0.03	0.11	no							
	1960-1969 n=240	0.13	0.01	yes							
	1970-1979 n=240	0.06	0.02	no							
	1980-1993 n=336	0.27	0.06	yes							
Chase Prairie	1941-1949 n=216	-0.26	0.12	yes	2, 3, 4	3, 4, 5	3, 4	2, 3, 4	3, 4	3, 4	1, 2, 3, 4
	1950-1959 n=240	-0.03	0.04	no							
	1960-1969 n=240	0.02	0.01	no							
	1970-1979 n=240	0.10	0.03	yes							
	1980-1993 n=336	0.08	0.05	yes							

Table 3-6--continued.

Station	Interval and Sample Size	Mean Water Depth Change (With sill-No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
Chesser Prairie	1941-1949 n=216	-0.04	0.02	no	7	6, 7	7	7	7	7	6, 7
	1950-1959 n=240	0.15	0.26	yes							
	1960-1969 n=240	-0.02	0.00	no							
	1970-1979 n=240	-0.02	0.01	no							
	1980-1993 n=336	0.05	0.01	no							
Coffee Bay	1941-1949 n=216	-0.03	0.02	no	5, 6	5, 6	5, 6	5, 6	6	6, 7	5, 6
	1950-1959 n=240	0.07	0.11	yes							
	1960-1969 n=240	-0.02	0.00	no							
	1970-1979 n=240	-0.02	0.01	no							
	1980-1993 n=336	0.05	0.02	no							

Table 3-6--continued.

Station	Interval and Sample Size	Mean Water Depth Change (With sill- No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
Craven's Hammock	1941-1949 n=216	0.15	0.04	yes	3, 4, 5	3, 4, 5, 6	4, 5	3, 4, 5	3, 4, 5	4, 5	4, 5, 6
	1950-1959 n=240	-0.14	0.08	yes							
	1960-1969 n=240	-0.02	0.00	no							
	1970-1979 n=240	-0.12	0.03	yes							
	1980-1993 n=336	0.21	0.05	yes							
Cypress Creek	1941-1949 n=216	-0.08	0.08	yes	1, 2, 3, 4	4, 5, 6	1	1, 2, 3, 4	4, 5	5, 6, 7	3, 4, 5
	1950-1959 n=240	0.03	0.07	no							
	1960-1969 n=240	0.05	0.01	no							
	1970-1979 n=240	0.00	0.00	no							
	1980-1993 n=336	0.44	0.15	yes							

Table 3-6--continued.

Station	Interval and Sample Size	Mean Water Depth Change (With sill-No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
Double Lakes	1941-1949 n=216	-0.13	0.05	yes	3, 4, 5	3, 4, 5	4, 5	3, 4, 5	3, 4, 5	4, 5	3, 4, 5
	1950-1959 n=240	-0.03	0.04	no							
	1960-1969 n=240	0.00	0.00	no							
	1970-1979 n=240	0.02	0.02	no							
	1980-1993 n=336	0.02	0.02	no							
Durdin Prairie	1941-1949 n=216	-0.01	0.02	no	5, 6	5, 6	5, 6	5, 6	5, 6	5, 6	5, 6
	1950-1959 n=240	-0.01	0.02	no							
	1960-1969 n=240	-0.01	0.00	no							
	1970-1979 n=240	0.08	0.03	yes							
	1980-1993 n=336	0.03	0.01	no							

Table 3-6--continued.

Station	Interval and Sample Size	Mean Water Depth Change (With sill-No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
Floyd's Prairie	1941-1949 n=216	-0.09	0.03	yes	3, 4, 5	4, 5, 6	3, 4, 5	3, 4, 5	4, 5	4, 5	3, 4, 5
	1950-1959 n=240	-0.02	0.05	no							
	1960-1969 n=240	0.06	0.02	yes							
	1970-1979 n=240	0.00	0.00	no							
	1980-1993 n=336	0.16	0.08	yes							
Gannett Lake	1941-1949 n=216	-0.03	0.02	no	6	5, 6	6	6	6	6	5, 6
	1950-1959 n=240	0.01	0.07	no							
	1960-1969 n=240	-0.03	0.00	no							
	1970-1979 n=240	-0.03	0.00	no							
	1980-1993 n=336	0.01	0.01	no							

Table 3-6--continued.

Station	Interval and Sample Size	Mean Water Depth Change (With sill- No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
Moonshine Ridge	1941-1949 n=216	-0.03	0.02	no	4, 5, 6	4, 5, 6	5, 6	4, 5	5, 6	5, 6	4, 5, 6
	1950-1959 n=240	0.04	0.10	no							
	1960-1969 n=240	-0.02	0.00	no							
	1970-1979 n=240	-0.02	0.01	no							
	1980-1993 n=336	0.05	0.02	no							
Suwannee River	1941-1949 n=216	-0.10	0.05	yes	5, 6	6	5, 6	5, 6	5, 6	6	5, 6
	1950-1959 n=240	0.06	0.05	yes							
	1960-1969 n=240	0.22	0.01	yes							
	1970-1979 n=240	0.10	0.02	yes							
	1980-1993 n=336	0.29	0.06	yes							

Table 3-6--continued.

Station	Interval and Sample Size	Mean Water Depth Change (With sill-No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
Sapling Prairie	1941-1949 n=216	0.00	0.02	no	3, 4, 5	4, 5, 6	4, 5	3, 4, 5	4, 5	4, 5	3, 4, 5
	1950-1959 n=240	-0.03	0.06	no							
	1960-1969 n=240	0.03	0.02	no							
	1970-1979 n=240	0.17	0.07	yes							
	1980-1993 n=336	0.12	0.07	yes							
Sapp Prairie	1941-1949 n=216	-0.21	0.15	yes	3, 4, 5	4, 5, 7	1, 2, 3, 4	1, 2, 3, 4	3, 4, 5	5, 6, 7	3, 4, 5
	1950-1959 n=240	-0.14	0.24	yes							
	1960-1969 n=240	0.03	0.01	no							
	1970-1979 n=240	0.29	0.12	yes							
	1980-1993 n=336	0.30	0.12	yes							

Table 3-6--continued.

Station	Interval and Sample Size	Mean Water Depth Change (With sill-No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
SCFSP	1941-1949 n=216	-0.14	0.05	yes	4, 5	5, 6	4, 5	4, 5	4, 5	5, 6	4, 5
	1950-1959 n=240	-0.02	0.09	no							
	1960-1969 n=240	0.15	0.02	yes							
	1970-1979 n=240	0.06	0.02	no							
	1980-1993 n=336	0.32	0.07	yes							
SCRA	1941-1949 n=216	-0.03	0.01	no	5	5	5	5	5, 6	5, 6	5
	1950-1959 n=240	0.05	0.13	yes							
	1960-1969 n=240	-0.02	0.00	no							
	1970-1979 n=240	-0.02	0.00	no							
	1980-1993 n=336	0.01	0.01	no							

Table 3-6--continued.

Station	Interval and Sample Size	Mean Water Depth Change (With sill- No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
Sill Gate (South)	1941-1949 n=216	-0.27	0.06	yes	4, 5, 6	5, 6	4, 5	4, 5	4, 5	5, 6	4, 5
	1950-1959 n=240	-0.07	0.02	yes							
	1960-1969 n=240	0.08	0.01	yes							
	1970-1979 n=240	-0.06	0.04	no							
	1980-1993 n=336	0.28	0.09	yes							
Sweetwater Creek	1941-1949 n=216	-0.29	0.12	yes	5, 6	5, 6, 7	5	5	5, 6	6	5
	1950-1959 n=240	0.02	0.05	no							
	1960-1969 n=240	0.04	0.01	no							
	1970-1979 n=240	0.09	0.04	no							
	1980-1993 n=336	0.06	0.02	yes							

Table 3-6--continued.

Station	Interval and Sample Size	Mean Water Depth Change (With sill-No Sill) (m)	Standard Deviation	With- and No-Sill Hydroperiod Frequencies Significantly Different? (P=0.05)	Most Frequent Hydroperiod Groups, No Sill	Most Frequent Hydroperiod Groups, With Sill	Most Frequent Hydroperiod Groups With Sill Simulation 1941-1949	Most Frequent Hydroperiod Groups With Sill Simulation 1950-1959	Most Frequent Hydroperiod Groups No Sill Simulation 1960-1969	Most Frequent Hydroperiod Groups No Sill Simulation 1970-1979	Most Frequent Hydroperiod Groups No Sill Simulation 1980-1993
Territory Prairie	1941-1949 n=216	-0.15	0.06	yes	4, 5	4, 5, 6	5	4, 5	4, 5	4, 5	4, 5
	1950-1959 n=240	-0.02	0.02	no							
	1960-1969 n=240	-0.01	0.00	no							
	1970-1979 n=240	-0.01	0.00	no							
	1980-1993 n=336	0.21	0.09	yes							
Transect 60	1941-1949 n=216	0.15	0.03	yes	5, 6	6	5, 6	5, 6	6	6, 7	5, 6
	1950-1959 n=240	-0.09	0.03	yes							
	1960-1969 n=240	0.05	0.01	yes							
	1970-1979 n=240	-0.32	0.06	yes							
	1980-1993 n=336	0.14	0.06	yes							

hydroperiod group frequencies (Table 3-6). There were also areas with as little as 0.06 m increase in average water depth that had significant changes in hydroperiod group frequencies (Figure 3-17). Whether these changes are significant to the swamp vegetation composition most likely depends on the timing and type of hydroperiod changes occurring (See Chapters 6 and 7).

Changes in frequencies of water depths measured in the 7 "hydroperiod groups" with and without the sill present during 1941-1993 generally were experienced in the Suwannee River drainage area in the western half of the swamp, but not in the eastern swamp (Figure 3-18). The areas surrounding recorders in Billy's Lake, SCFSP, Floyd's Prairie, Sapling Prairie, Craven's Hammock, Suwannee River, Sill Gate, Transect 60, Cypress Creek, Sapp Prairie, and Chase Prairie had longer periods of slightly deeper water depths during 1960-1993 (with-sill) than during 1941-1959 (no-sill) (Table 3-6), with greatest duration of flooding occurring during 1970-1979. All areas experienced elevated water levels and prolonged hydroperiods during 1970-1979 regardless of the sill condition (sill present or absent in model simulations). Similarly, during 1980-1993 and 1950-1959 water levels were comparatively lower in all parts of the swamp regardless of the sill's presence in the model simulation (Table 3-6). Although inundation duration was also slightly greater during 1970-1979 than other intervals at Sweetwater Creek, inundation depths and frequencies in the remaining areas (Coffee Bay, Sweetwater Creek, SCRA, Chesser Prairie, Gannett Lake, Durdin Prairie, Double Lakes, Moonshine Ridge, and Territory Prairie) did not change during 1941-1993 with the addition of the sill during 1960-1993 (Table 3-6). During the simulated "no-sill" condition of 1960-

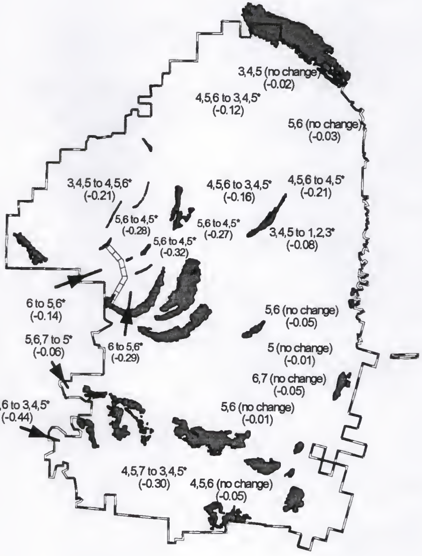


Figure 3-17. Changes in most frequent hydroperiod groups during 1980-1993, with sill removal. Numbers represent the most frequent with-sill hydroperiod groups (see Tables 3-5 and 3-6) versus most frequent no-sill hydroperiod groups. Areas with significant change are marked with *. Average semi-monthly water depth decrease with sill removal is noted in ( ).

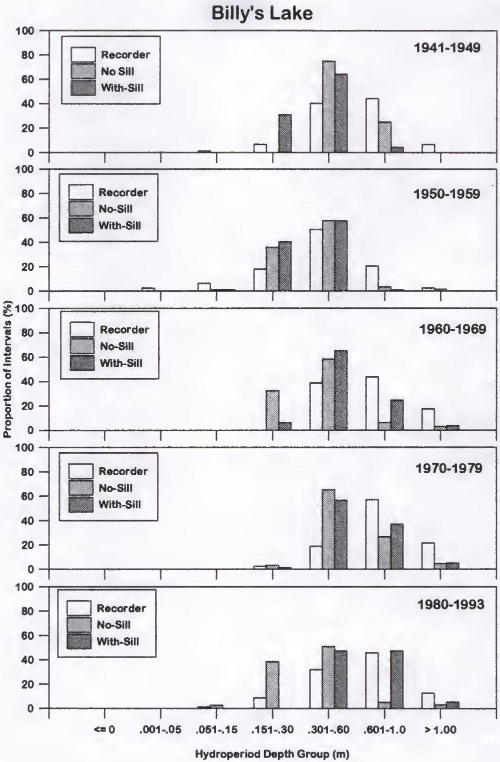
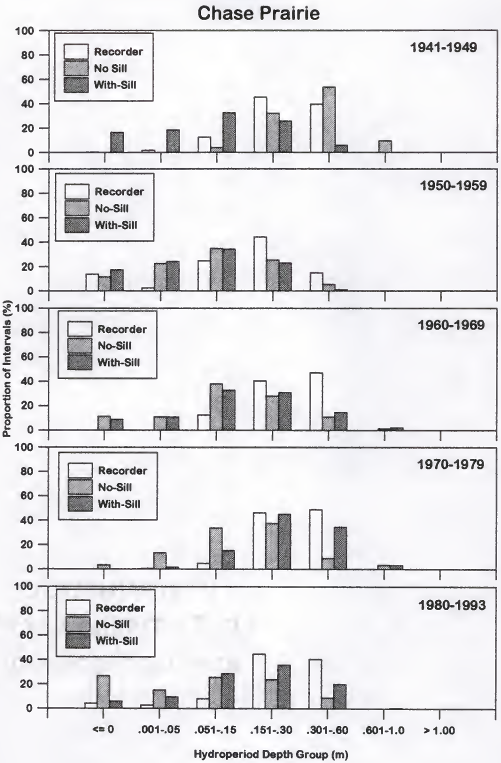


Figure 3-18. Changes in hydroperiod depth group frequencies with and without the sill during 1941-1993, by decade intervals.



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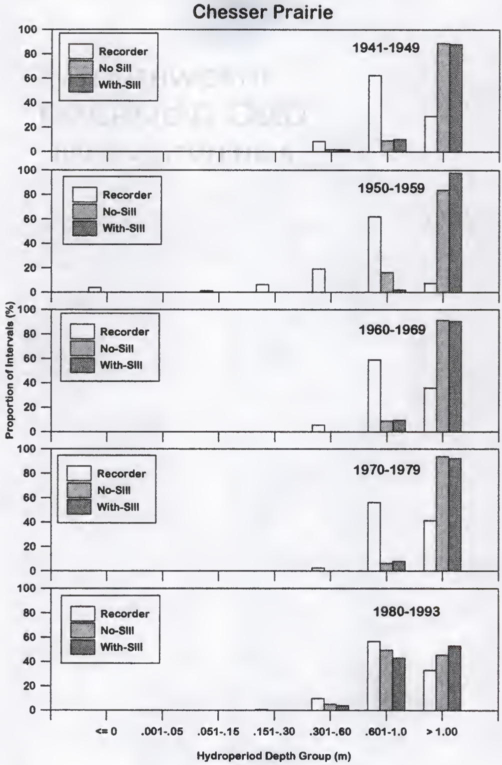

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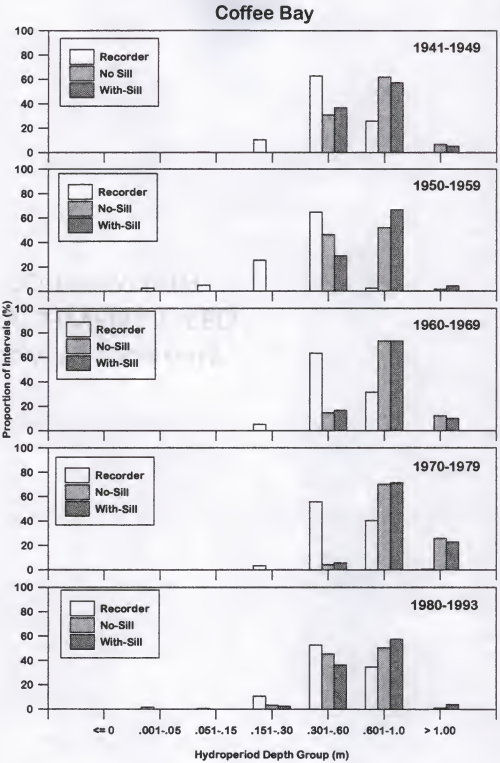

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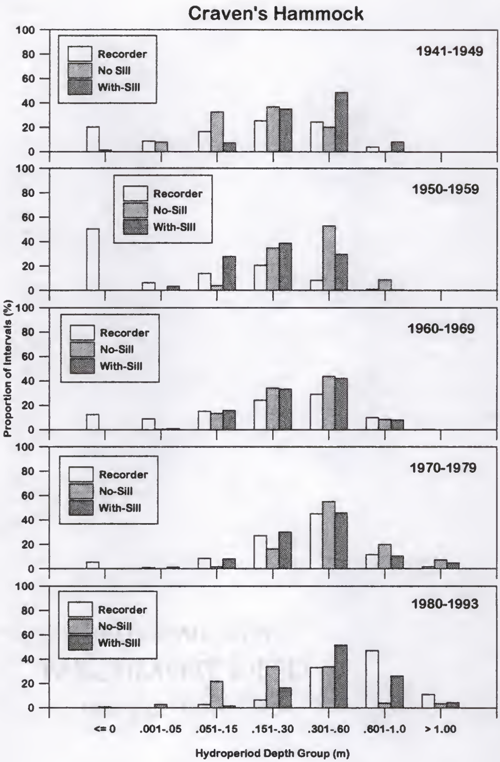

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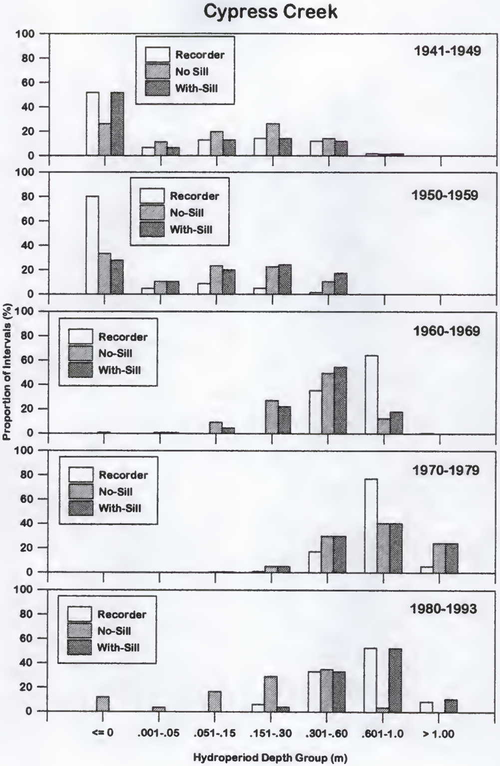

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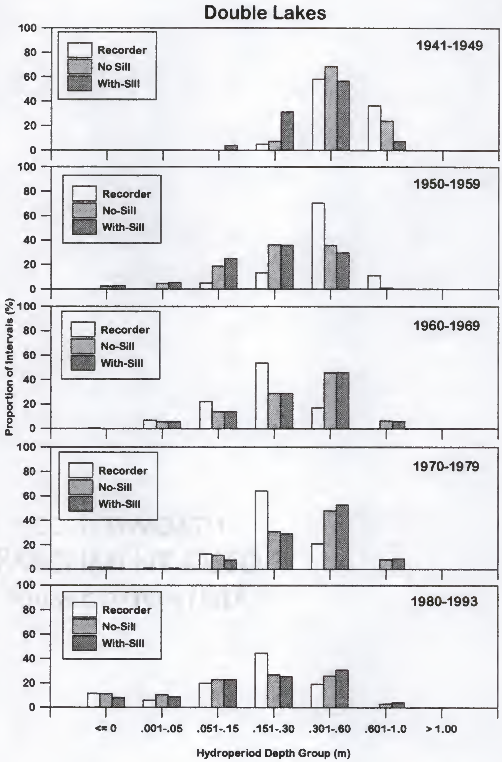

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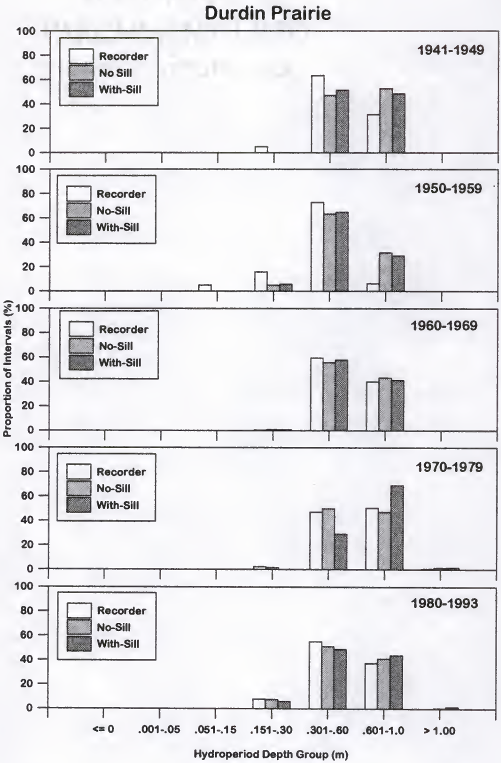

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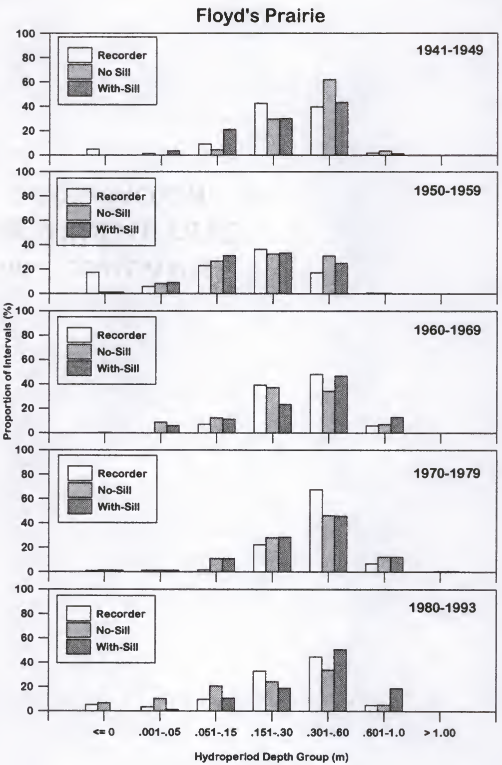

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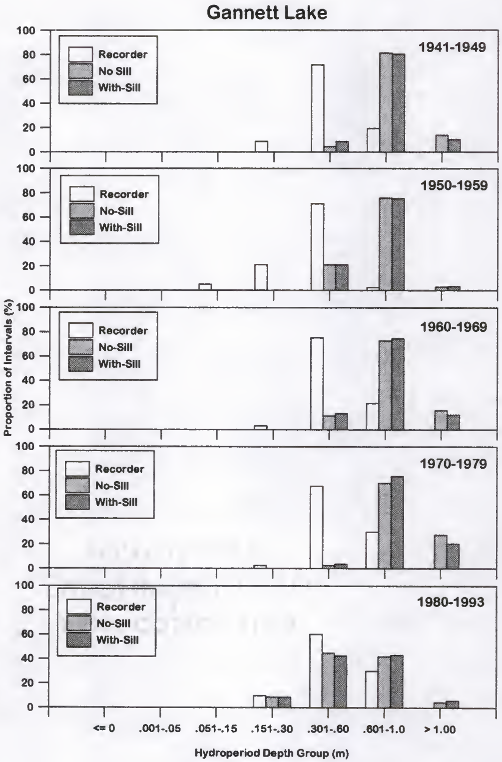

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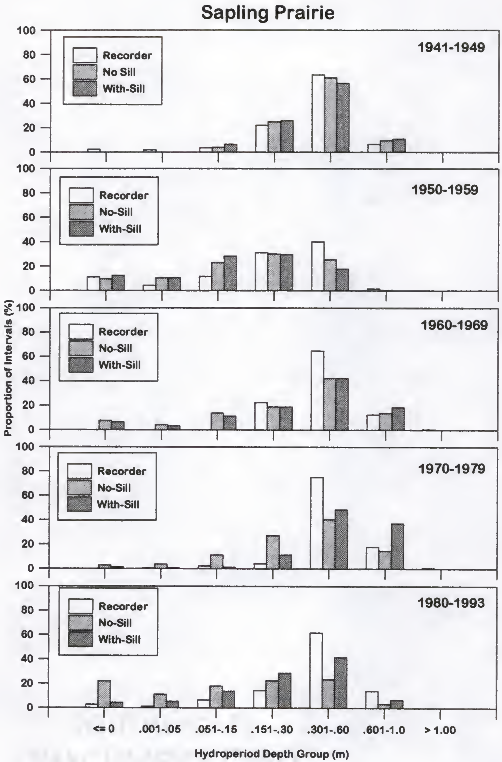

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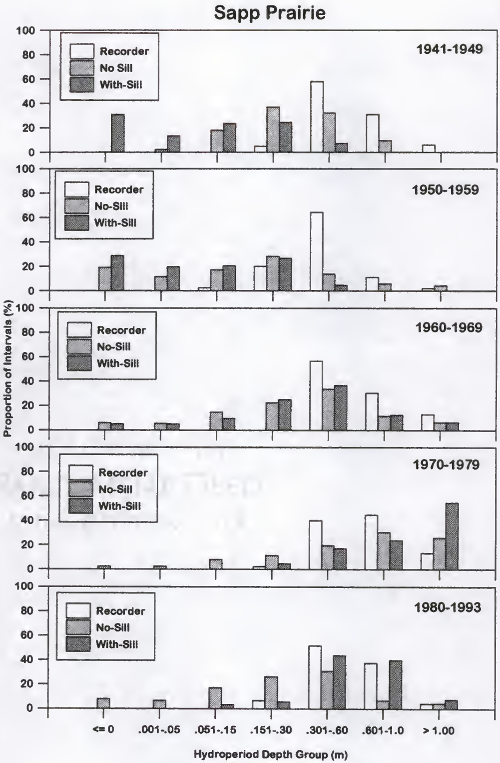

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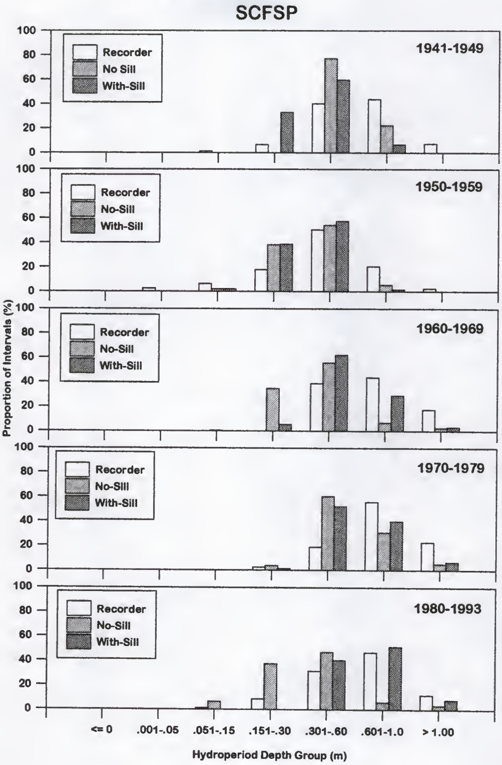

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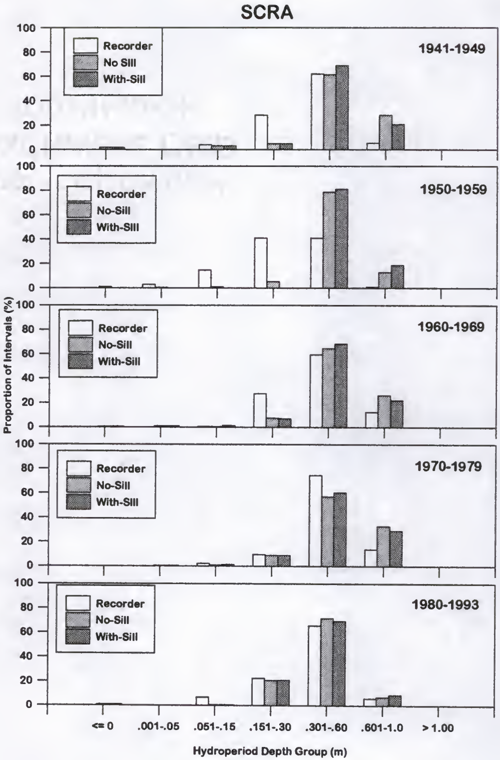

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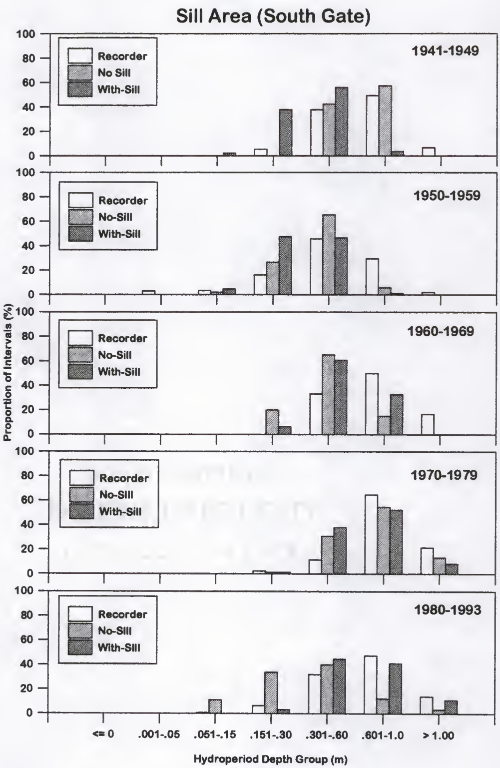

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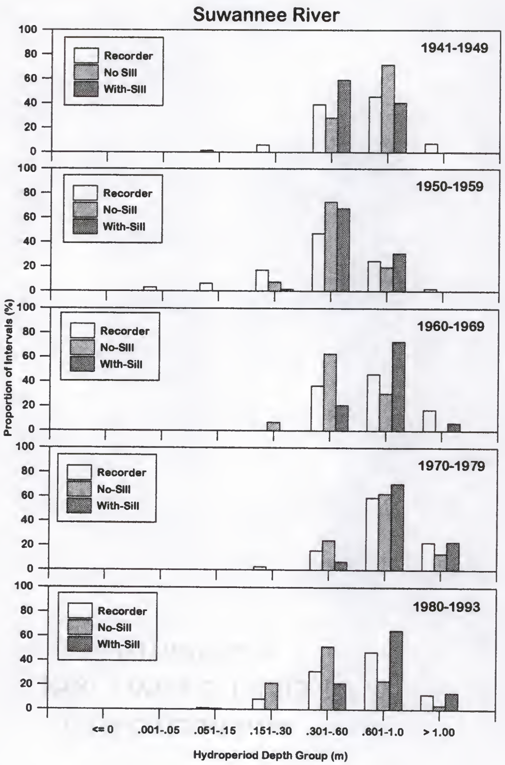

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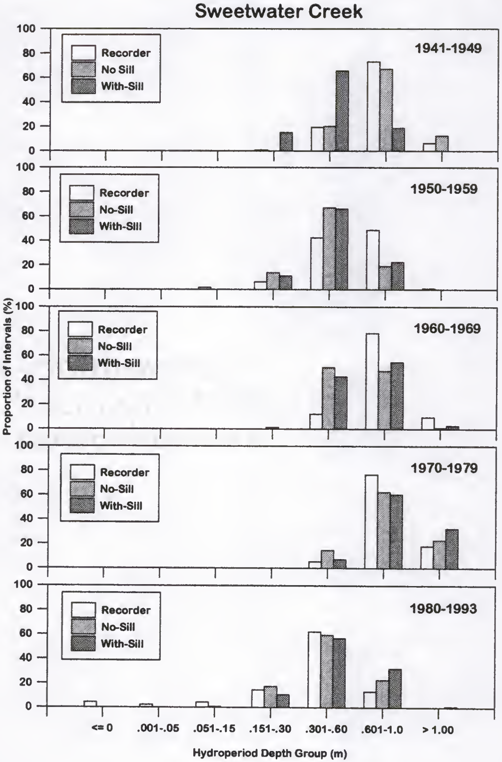

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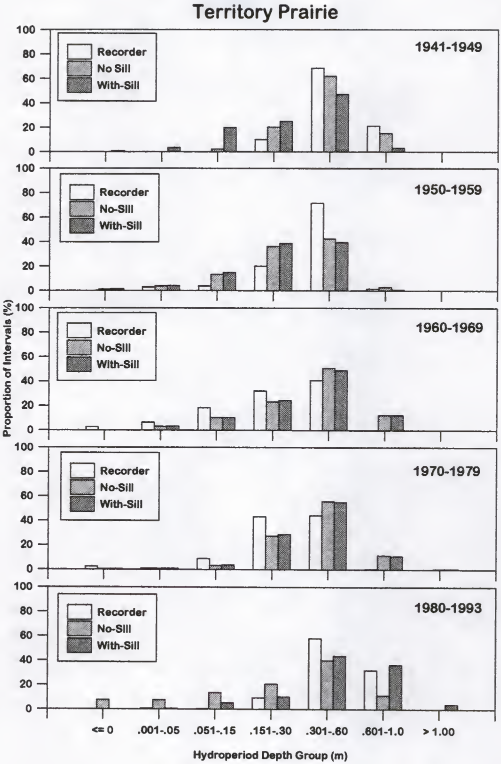


Figure 3-18--continued.

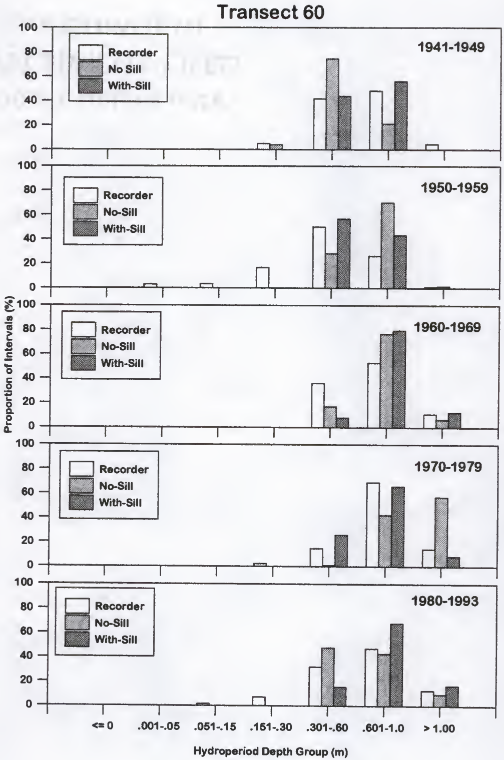


Figure 3-18--continued.

1993 and the "with-sill" condition of 1941-1959, frequencies of water depths in each hydroperiod depth group indicated a similar sill impact area. No changes in inundation duration, or hydroperiod, were indicated at Sweetwater Creek, Territory Prairie, Coffee Bay, SCRA, Chesser Prairie, Gannett Lake, Durdin Prairie, Double Lakes, and Moonshine Ridge when the sill was added to the 1941-1959 model runs or removed from the 1961-1993 iterations (Table 3-6). Slightly lower water depths and shorter inundation intervals occurred in the remainder of the check station areas when the sill was removed from the 1960-1993 model iterations; longer flooding periods were recorded in these areas when the sill was added to the 1941-1959 simulations (Figure 3-18).

During 1941-1949 and 1980-1993 the presence of the sill increased hydroperiods during both the growing and non-growing seasons in the area encompassed by Craven's Hammock, Floyd's Prairie, Lower Territory Prairie and western Chase Prairie, SCFSP, and Transect 60 (Figure 3-7). During the 1950-1979 "with-sill" simulation, the area affected during the growing and non-growing seasons was primarily in the vicinity of the sill and Pocket area; fewest stations were affected during 1950-1959 (Table 3-7).

Regional Hydrologic Trends

Changes in relationships between the water levels in the sill area and throughout the swamp occurring with sill removal and at various water level conditions do not necessarily result in significant changes in hydroperiods. Comparisons of correlation relationships between the sill area and locations throughout the swamp under a range of water level conditions with and without the sill present suggested changes not apparent in

Table 3-7. Comparison of changes in growing season and non-growing season hydroperiod group frequencies in with-sill and no-sill model simulations, 1941-1993. Stations with poor with-sill versus recorder agreement in 1980-1993 are omitted.

Station	1941-1949 Growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1941-1949 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1950-1959 Growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1950-1959 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1960-1969 Growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1960-1969 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1970-1979 Growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1970-1979 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1980-1993 Growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1980-1993 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)
Billy's Lake	yes	yes	no	no	yes	yes	no	no	yes	yes
Chase Prairie	yes	yes	no	no	no	no	yes	yes	yes	yes
Chesser Prairie	no	no	yes	no	no	no	no	no	no	no
Coffee Bay	no	no	no	no	no	no	no	no	no	no
Craven's Hammock	yes	yes	yes	yes	no	no	yes	no	yes	yes
Cypress Creek	yes	yes	no	no	no	no	no	no	yes	yes
Double Lakes	yes	yes	no	no	no	no	no	no	no	no
Durdin Prairie	no	no	no	no	no	no	yes	no	no	no
Floyd's Prairie	yes	yes	no	no	yes	no	no	no	yes	yes
Gannett Lake	no	no	no	no	no	no	no	no	no	no

Table 3-7--continued.

Station	1941-1949 Growing[a] Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1941-1949 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1950-1959 Growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1950-1959 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1960-1969 Growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1960-1969 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1970-1979 Growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1970-1979 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1980-1993 Growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)	1980-1993 Non-growing Season With-sill and No-sill Hydroperiods Significantly Different? (P=0.05)
Moonshine Ridge	no	no	no	no	no	no	no	no	no	no
Suwannee River	yes	no	yes	no	yes	yes	yes	no	yes	yes
Sapling Prairie	no	no	no	no	no	no	yes	yes	yes	yes
Sapp Prairie	yes	yes	yes	yes	no	no	yes	yes	yes	yes
SCFSP	yes	yes	no	no	yes	yes	no	no	yes	yes
SCRA	no	no	yes	yes	no	no	no	no	no	no
Sill Gate (South)	yes	yes	yes	no	yes	yes	yes	yes	yes	yes
Sweetwater Creek	yes	yes	no	no	no	no	no	no	no	no
Territory Prairie	yes	yes	no	no	no	no	no	no	yes	yes
Transect 60	yes	yes	yes	no	no	no	yes	yes	yes	yes

[a] Growing season is March-October; non-growing season is November-February.

comparisons of hydroperiod depth group frequencies. The significance of these hydrologic changes to swamp vegetation communities depends on species' tolerances (see Chapters 6 and 7).

Trends in water levels and hydroperiods demonstrated with the hydrology model manipulations reflect the basin delineations determined with the topographic surface, vegetation maps, and water level recorder data. The Northwest basin represented by check stations at Billy's Lake, SCFSP, Suwannee River, Cravens Hammock, Sapling Prairie, Floyd's Prairie, and Transect 60, showed the greatest response to the sill's presence. Removal of the sill resulted in a downward shift of hydroperiod group frequencies of 1-3 classes (Figure 3-18). During low and average water levels, absence of the sill permitted greater fluctuations in water levels, and greater difference between the sill area and the remainder of the basin (Table 3-8). During high water conditions without the sill, this difference was not as great; the natural topography southwest of the sill restricts water flow from the area, creating a sill-like impoundment in the river floodplain as water leaves the swamp (Figure 2-20). The result is a condition similar to that of the natural sill at the southwest end of Billy's Lake and the constructed sill; the natural impoundment slows drainage from the area and creates pooling above the topographic rise or berm until water surface elevations exceed the crest, when overflow occurs. There is a similar berm southwest of Cypress Creek that impounds water in the river above it and may be creating the backwater effects noted in the Cypress Creek basin (Figure 3-15).

Table 3-8. Comparison of water depths and changes at the south Sill Gate and other check stations throughout the Okefenokee Swamp during 1980-1993 with-sill, no-sill, and no outflow model simulations.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
Billy's Lake	With Sill	Low	25	0.38	0.04	0.0284	0.1272	0.5673
		Average	264	0.62	0.16	0.6807	0.8643	0.0001
		High	26	0.90	0.14	0.0363	0.2085	0.7278
		Very High	21	1.17	0.26	0.5641	1.9718	0.0001
	No Sill	Dry	106	0.21	0.04	0.6275	0.6872	0.0001
		Low	82	0.31	0.05	0.4198	0.9425	0.0001
		Average	135	0.49	0.14	0.4437	0.7849	0.0001
		High	5	1.01	0.36	0.1752	2.4603	0.5703
		Very High	8	1.22	0.20	0.3136	1.5040	0.0864
	No Outflow	Average	3	0.97	0.42	0.9954	5.0545	0.0305
		High	19	0.89	0.25	0.0293	0.9100	0.4943
		Very High	120	1.05	0.13	0.1811	0.5406	0.0001
		Flooded	194	1.32	0.15	0.5493	0.7528	0.0001
Chase Prairie	With Sill	Low	25	0.02	0.04	0.0783	0.2622	0.0947
		Average	264	0.18	0.11	0.6143	0.5482	0.0001
		High	26	0.38	0.11	0.1076	-0.8632	0.0566
		Very High	21	0.43	0.09	0.0703	0.3161	0.1295

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
	No Sill	Dry	106	0.01	0.04	0.1170	0.1503	0.0002
		Low	82	0.06	0.05	0.1447	0.5517	0.0002
		Average	135	0.21	0.10	0.5836	0.6077	0.0001
		High	5	0.37	0.13	0.1228	-1.0516	0.5077
		Very High	8	1.22	0.09	0.1412	0.5540	0.1928
	No Outflow	Average	3	0.16	0.28	0.9929	-3.3673	0.0380
		High	19	0.07	0.17	0.0563	0.1788	0.8425
		Very High	120	0.10	0.10	0.0391	0.2122	0.0175
		Flooded	194	0.29	0.14	0.6232	0.7641	0.0001
Chesser Prairie	With Sill	Low	25	0.65	0.11	0.0629	0.9980	0.1198
		Average	264	1.02	0.20	0.4569	0.9035	0.0001
		High	26	1.24	0.22	0.3510	-2.7638	0.0008
		Very High	21	1.22	0.13	0.0358	-0.1654	0.5851
	No Sill	Dry	106	0.77	0.17	0.3144	2.0258	0.0001
		Low	82	0.93	0.15	0.0119	0.6875	0.1635
		Average	135	1.14	0.16	0.0814	0.3928	0.0005
		High	5	1.00	0.09	0.0064	0.8611	0.3963
		Very High	8	1.14	0.05	0.5754	0.4280	0.0177

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
	No Outflow	Average	3	0.62	0.10	0.9338	-1.2204	0.1164
		High	19	0.68	0.09	0.2750	1.1398	0.0124
		Very High	120	0.97	0.15	0.2119	0.7030	0.0001
		Flooded	194	1.23	0.20	0.4567	0.9026	0.0001
Coffee Bay	With Sill	Low	25	0.34	0.06	0.1170	0.5950	0.0525
		Average	264	0.66	0.16	0.6826	0.8727	0.0001
		High	26	0.83	0.22	0.3483	-2.7199	0.0009
		Very High	21	0.85	0.13	0.0352	0.3572	0.2040
	No Sill	Dry	106	0.43	0.10	0.5030	1.5168	0.0001
		Low	82	0.58	0.09	0.1262	0.9618	0.0006
		Average	135	0.77	0.13	0.0976	0.3336	0.0001
		High	5	0.71	0.04	0.0158	0.3611	0.4043
		Very High	8	0.88	0.05	0.7510	0.5460	0.0033
	No Outflow	Average	3	0.37	0.14	0.9949	-1.6256	0.0321
		High	19	0.41	0.11	0.0883	0.8818	0.1160
		Very High	120	0.61	0.11	0.2585	0.5768	0.0001
		Flooded	194	0.86	0.16	0.4413	0.7400	0.0001

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
Craven's Hammock	With Sill	Low	25	0.22	0.07	0.0313	0.1934	0.6078
		Average	264	0.47	0.16	0.7475	0.9212	0.0001
		High	26	0.82	0.13	0.0811	0.9300	0.0860
		Very High	21	1.14	0.25	0.6247	1.9874	0.0001
	No Sill	Dry	106	0.12	0.06	0.3457	0.7399	0.0001
		Low	82	0.22	0.05	0.4410	1.0728	0.0001
		Average	135	0.45	0.13	0.7747	0.9713	0.0001
		High	5	1.01	0.18	0.2697	-0.8016	0.7240
		Very High	8	1.23	0.13	0.5968	1.2480	0.0150
	No Outflow	Average	3	0.69	0.36	0.9929	-4.2607	0.0380
		High	19	0.61	0.25	0.0298	0.9046	0.4984
		Very High	120	0.76	0.15	0.1157	0.5219	0.0001
		Flooded	194	1.05	0.19	0.4041	0.8398	0.0001
Cypress Creek	With Sill	Low	25	0.57	0.14	0.0311	-1.0300	0.1965
		Average	264	0.73	0.23	0.0761	0.4245	0.0001
		High	26	0.68	0.35	0.2793	-3.9267	0.0032
		Very High	21	0.53	0.21	0.0161	-0.5265	0.2638

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
	No Sill	Dry	106	0.11	0.12	0.1030	0.8303	0.0005
		Low	82	0.23	0.14	0.0369	0.9162	0.0462
		Average	135	0.38	0.16	0.0591	0.3430	0.0026
		High	5	0.29	0.02	0.5349	0.3770	0.0988
		Very High	8	0.43	0.06	0.9510	0.6520	0.0001
	No Outflow	Average	3	0.08	0.12	0.9801	-1.4739	0.0636
		High	19	0.14	0.10	0.0979	0.8794	0.1038
		Very High	120	0.37	0.16	0.0486	0.3767	0.0089
		Flooded	194	0.53	0.21	0.1156	0.4926	0.0001
Double Lakes	With Sill	Low	25	0.01	0.02	0.2438	0.3040	0.0071
		Average	264	0.22	0.15	0.8274	0.8962	0.0001
		High	26	0.43	0.12	0.1556	-1.0407	0.0263
		Very High	21	0.62	0.15	0.6378	1.2402	0.0001
	No Sill	Dry	106	0.04	0.04	0.5307	0.5996	0.0001
		Low	82	0.15	0.05	0.5257	1.0243	0.0001
		Average	135	0.36	0.10	0.4596	0.5616	0.0001
		High	5	0.58	0.06	0.1847	0.3810	0.5829
		Very High	8	0.76	0.07	0.8291	0.7460	0.0010

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
	No Outflow	Average	3	0.16	0.27	0.9966	-3.2678	0.0264
		High	19	0.09	0.18	0.0525	0.3027	0.7529
		Very High	120	0.15	0.15	0.0198	0.2477	0.0675
		Flooded	194	0.37	0.17	0.3678	0.6939	0.0001
Durdin Prairie	With Sill	Low	25	0.31	0.05	0.6433	1.0919	0.0001
		Average	264	0.57	0.16	0.7045	0.8633	0.0001
		High	26	0.81	0.16	0.1874	-1.5326	0.0157
		Very High	21	0.87	0.07	0.1794	0.3189	0.0318
	No Sill	Dry	106	0.38	0.09	0.4952	1.2707	0.0001
		Low	82	0.51	0.07	0.2980	1.0744	0.0001
		Average	135	0.72	0.53	0.3943	0.5854	0.0001
		High	5	0.80	0.03	0.1465	0.2262	0.5347
		Very High	8	0.87	0.05	0.0029	0.2140	0.3513
	No Outflow	Average	3	0.40	0.19	0.9960	-2.2820	0.0286
		High	19	0.37	0.15	0.0193	0.6438	0.4280
		Very High	120	0.51	0.14	0.0734	0.3835	0.0016
		Flooded	194	0.73	0.17	0.4761	0.7801	0.0001

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
Floyd's Prairie	With Sill	Low	25	0.09	0.04	0.0966	0.3608	0.0716
		Average	264	0.39	0.15	0.7028	0.8151	0.0001
		High	26	0.66	0.07	0.0284	0.3420	0.2009
		Very High	21	0.80	0.06	0.5560	0.4848	0.0001
	No Sill	Dry	106	0.06	0.05	0.6272	0.8697	0.0001
		Low	82	0.19	0.07	0.3017	1.1396	0.0001
		Average	135	0.41	0.11	0.6926	0.7287	0.0001
		High	5	0.63	0.03	0.0029	0.3333	0.3934
		Very High	8	0.80	0.06	0.7319	0.5780	0.0042
	No Outflow	Average	3	0.24	0.23	0.9867	-2.7109	0.0519
		High	19	0.25	0.15	0.0837	1.1897	0.1224
		Very High	120	0.47	0.12	0.3461	0.7030	0.0001
		Flooded	194	0.77	0.15	0.6520	0.7952	0.0001
Gannett Lake	With Sill	Low	25	0.26	0.05	0.0417	0.3955	0.1661
		Average	264	0.59	0.17	0.7779	0.9718	0.0001
		High	26	0.91	0.11	0.1312	-0.9137	0.0389
		Very High	21	1.04	0.09	0.5403	0.6996	0.0001

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
	No Sill	Dry	106	0.38	0.10	0.4782	1.4945	0.0001
		Low	82	0.53	0.09	0.0980	0.9133	0.0024
		Average	135	0.77	0.13	0.4376	0.7167	0.0001
		High	5	0.89	0.05	0.4405	0.7738	0.1344
		Very High	8	1.09	0.06	0.9057	0.7160	0.0002
	No Outflow	Average	3	0.31	0.17	0.9338	-1.9526	0.1164
		High	19	0.33	0.16	0.0274	0.6120	0.4808
		Very High	120	0.49	0.13	0.1640	0.5488	0.0001
		Flooded	194	0.80	0.18	0.6408	0.9867	0.0001
Moonshine Ridge	With Sill	Low	25	0.06	0.07	0.1093	0.7482	0.0590
		Average	264	0.43	0.17	0.5065	0.8027	0.0001
		High	26	0.58	0.24	0.2938	-2.7866	0.0025
		Very High	21	0.59	0.12	0.1174	0.4655	0.0709
	No Sill	Dry	106	0.20	0.14	0.3036	1.9504	0.0001
		Low	82	0.34	0.12	0.0427	0.8190	0.0347
		Average	135	0.52	0.15	0.0807	0.3587	0.0005
		High	5	0.45	0.03	0.2870	0.4444	0.2046
		Very High	8	0.62	0.06	0.9115	0.7340	0.0001

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
	No Outflow	Average	3	0.10	0.18	0.9929	-2.1303	0.0380
		High	19	0.09	0.13	0.0200	0.7484	0.2583
		Very High	120	0.37	0.12	0.4054	0.7801	0.0001
		Flooded	194	0.61	0.18	0.3338	0.7001	0.0001
Suwannee River	With Sill	Low	25	0.49	0.03	0.2535	0.4027	0.0060
		Average	264	0.73	0.13	0.8998	0.8018	0.0001
		High	26	1.06	0.08	0.2613	0.8990	0.0045
		Very High	21	1.29	0.16	0.0644	1.3080	0.0001
	No Sill	Dry	106	0.28	0.05	0.8958	0.9590	0.0001
		Low	82	0.41	0.04	0.7715	1.1050	0.0001
		Average	135	0.63	0.11	0.9141	0.8333	0.0001
		High	5	1.04	0.08	0.2825	0.3214	0.7530
		Very High	8	1.26	0.10	0.7672	1.0200	0.0027
	No Outflow	Average	3	1.02	0.16	0.9983	1.9621	0.0186
		High	19	1.21	0.06	0.8355	1.1966	0.0001
		Very High	120	1.55	0.09	0.9020	0.8830	0.0001
		Flooded	194	1.87	0.14	0.9686	0.9096	0.0001

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
Sapling Prairie	With Sill	Low	25	0.03	0.04	0.0078	0.1930	0.3763
		Average	264	0.28	0.14	0.8260	0.8486	0.0001
		High	26	0.53	0.06	0.0210	0.1661	0.4926
		Very High	21	0.70	0.09	0.7473	0.7914	0.0001
	No Sill	Dry	106	0.01	0.03	0.2006	0.2723	0.0001
		Low	82	0.11	0.07	0.3110	1.1499	0.0001
		Average	135	0.32	0.10	0.6559	0.6819	0.0001
		High	5	0.60	0.06	0.3255	0.0873	0.9025
		Very High	8	0.77	0.07	0.7379	0.7000	0.0039
	No Outflow	Average	3	0.18	0.31	0.9929	-3.6422	0.0380
		High	19	0.08	0.20	0.0552	0.2576	0.8128
		Very High	120	0.11	0.14	0.0204	0.2418	0.0649
		Flooded	194	0.37	0.17	0.4215	0.7571	0.0001
Sapp Prairie	With Sill	Low	25	0.31	0.15	0.0552	-1.2779	0.1349
		Average	264	0.58	0.19	0.2728	0.6470	0.0001
		High	26	0.88	0.17	0.1333	1.4150	0.0376
		Very High	21	1.16	0.17	0.5603	1.3017	0.0001

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
	No Sill	Dry	106	0.10	0.10	0.2218	1.0230	0.0001
		Low	82	0.21	0.11	0.0288	0.6854	0.0688
		Average	135	0.46	0.22	0.5402	1.3377	0.0001
		High	5	1.17	0.18	0.1923	-1.1825	0.5933
		Very High	8	1.33	0.12	0.5226	1.1280	0.0258
	No Outflow	Average	3	0.45	0.79	0.9929	-9.3460	0.0380
		High	19	0.18	0.43	0.0525	0.7232	0.7533
		Very High	120	0.28	0.20	0.0435	0.4545	0.0127
		Flooded	194	0.56	0.26	0.2112	0.8036	0.0001
SCFSP	With Sill	Low	25	0.39	0.04	0.0136	0.2001	0.4189
		Average	264	0.66	0.16	0.7806	0.9265	0.0001
		High	26	0.96	0.13	0.0378	0.1531	0.7686
		Very High	21	1.22	0.24	0.6099	1.8508	0.0001
	No Sill	Dry	106	0.19	0.04	0.6454	0.7255	0.0001
		Low	82	0.30	0.05	0.4759	1.0561	0.0001
		Average	135	0.50	0.13	0.5208	0.7877	0.0001
		High	5	0.98	0.31	0.2050	-1.8968	0.6115
		Very High	8	1.21	0.18	0.3689	1.4280	0.0648

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
	No Outflow	Average	3	0.98	0.27	0.9929	-3.2299	0.0380
		High	19	0.97	0.19	0.0022	0.9804	0.3223
		Very High	120	1.18	0.11	0.3290	0.6373	0.0001
		Flooded	194	1.46	0.14	0.6952	0.7884	0.0001
SCRA	With Sill	Low	25	0.27	0.03	0.0527	0.2603	0.1400
		Average	264	0.43	0.12	0.3879	0.4769	0.0001
		High	26	0.48	0.21	0.3304	-2.5179	0.0013
		Very High	21	0.36	0.16	0.1335	-0.6515	0.0577
	No Sill	Dry	106	0.32	0.06	0.3770	0.7740	0.0001
		Low	82	0.41	0.05	0.2178	0.7329	0.0001
		Average	135	0.51	0.12	0.0000	0.0047	0.9566
		High	5	0.16	0.12	0.0636	1.0556	0.4473
		Very High	8	0.25	0.03	0.1725	0.1860	0.1679
	No Outflow	Average	3	0.17	0.15	0.9231	1.7038	0.1256
		High	19	0.27	0.10	0.0490	0.2037	0.6954
		Very High	120	0.40	0.10	0.0549	0.2361	0.0058
		Flooded	194	0.50	0.14	0.1910	0.4090	0.0001

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
Sill Gate (South)	With Sill	Low	25	0.30	0.04			
		Average	264	0.61	0.15			
		High	26	1.02	0.05			
		Very High	21	1.26	0.10			
	No Sill	Dry	106	0.17	0.05			
		Low	82	0.30	0.03			
		Average	135	0.53	0.12			
		High	5	0.98	0.05			
		Very High	8	1.23	0.08			
	No Outflow	Average	3	0.83	0.08			
		High	19	0.96	0.05			
		Very High	120	1.33	0.10			
		Flooded	194	1.67	0.15			
Sweetwater Creek	With Sill	Low	25	0.25	0.04	0.2235	0.5527	0.0099
		Average	264	0.52	0.15	0.7338	0.8362	0.0001
		High	26	0.70	0.19	0.2406	-1.9951	0.0064
		Very High	21	0.77	0.13	0.1673	0.6036	0.0373

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
	No Sill	Dry	106	0.29	0.08	0.5164	1.2153	0.0001
		Low	82	0.42	0.06	0.2292	0.9054	0.0001
		Average	135	0.61	0.11	0.2920	0.5086	0.0001
		High	5	0.64	0.05	0.3265	0.0714	0.9091
		Very High	8	0.81	0.09	0.7589	0.9400	0.0030
	No Outflow	Average	3	0.34	0.15	0.9987	-1.7559	0.0164
		High	19	0.33	0.13	0.0286	0.4624	0.4892
		Very High	120	0.48	0.12	0.1040	0.4061	0.0002
		Flooded	194	0.69	0.16	0.3700	0.6772	0.0001
Territory Prairie	With Sill	Low	25	0.17	0.12	0.1457	1.3642	0.0338
		Average	264	0.53	0.20	0.2684	0.6884	0.0001
		High	26	0.80	0.21	0.1774	-1.9267	0.0185
		Very High	21	0.77	0.09	0.0062	-0.1874	0.3611
	No Sill	Dry	106	0.12	0.13	0.3287	1.5441	0.0001
		Low	82	0.26	0.12	0.0516	0.8615	0.0226
		Average	135	0.49	0.15	0.3788	0.7819	0.0001
		High	5	0.64	0.04	0.0729	0.3175	0.4561
		Very High	8	0.71	0.05	0.1528	0.0700	0.7976

Table 3-8--continued.

Check Station	Model	Sill Gate General Water Level Condition[a]	Sample Size (n)	Average Water Depth at Check Station (m)	Standard Deviation	r^2_{adj} (X=Sill Gate Water Depth, Y=Check Station Water Depth)	Slope	P (Slope = 0)
Transect 60	No Outflow	Average	3	0.16	0.28	0.9929	-3.2986	0.0380
		High	19	0.10	0.18	0.0364	0.5791	0.5518
		Very High	120	0.27	0.16	0.1770	0.6946	0.0001
		Flooded	194	0.56	0.21	0.4644	0.9472	0.0001
	With Sill	Low	25	0.50	0.04	0.6269	0.8772	0.0001
		Average	264	0.76	0.13	0.9346	0.8157	0.0001
		High	26	1.12	0.06	0.5097	0.8241	0.0001
		Very High	21	1.31	0.09	0.8219	0.8358	0.0001
	No Sill	Dry	106	0.44	0.06	0.9481	1.2029	0.0001
		Low	82	0.59	0.04	0.7521	1.1199	0.0001
		Average	135	0.84	0.13	0.8832	0.9738	0.0001
		High	5	1.20	0.08	0.6694	1.4087	0.0569
		Very High	8	1.43	0.07	0.9154	0.7460	0.0001
	No Outflow	Average	3	0.92	0.22	0.9865	2.6422	0.0523
		High	19	1.10	0.05	0.6483	0.8553	0.0001
		Very High	120	1.45	0.10	0.9577	0.9243	0.0001
		Flooded	194	1.78	0.15	0.9875	1.0094	0.0001

Table 3-8--continued.

[a] Water level conditions were defined from slope changes on a plot of ranked sill gate water depths, and correspond to the following depth ranges:

Condition	Sill Gate Water Depth Range (m)
dry	depth ≤ 0.24
low	$0.25 <$ depth ≤ 0.35
average	$0.36 <$ depth ≤ 0.88
high	$0.89 <$ depth ≤ 1.02
very high	$1.03 <$ depth ≤ 1.46
flooded	depth > 1.46

The Central basin, represented by check stations in Chesser Prairie, Coffee Bay, Gannett Lake, and SCRA behaved independent of the sill's presence in all but the highest water levels (Figure 3-19). No significant changes in hydroperiod frequencies in this basin occurred with removal of the sill (Figure 3-18). Under low water conditions the river floodplain drains more rapidly than this area, which loses water primarily through evapotranspiration (see System Sensitivities section). Under average conditions water levels reflect those at the sill gate when the sill is in place slightly more than when it is removed, but not enough to change hydroperiod frequencies. Under extremely high water conditions drainage from this area is delayed, most likely as the head difference between this basin and the west basin declines. The slope relationship changes from positive to negative under these conditions, and this is exacerbated by the sill's presence. This suggests that under these conditions (occurring during 6% of 1980-1993), drainage may occur to an alternate basin, possibly towards the St. Marys River basin in the southeastern swamp. In "no-sill" model simulations water elevations reached this condition during 2% of 1980-1993. The Moonshine Ridge area, in the St. Marys River watershed, also demonstrates this shift in relationship with sill area water level fluctuations. Drainage of this area under extremely high water level conditions may occur more quickly than in the western and southwestern swamp due to the smaller volume of water collecting in the watershed (Figure 3-20), although a backwater effect may also be occurring in this basin as water accumulates in the St. Marys River.

Chase and Territory Prairie water levels, when very high, are also negatively correlated with those in the sill area when the sill is present (Figure 3-19). The

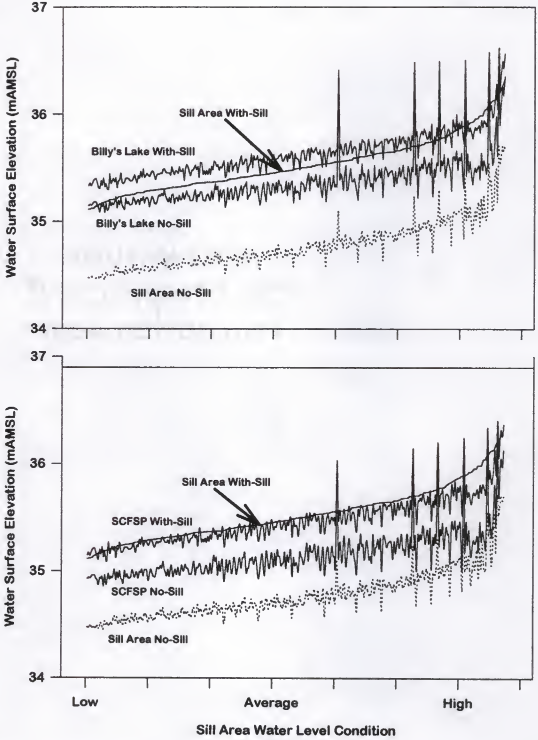
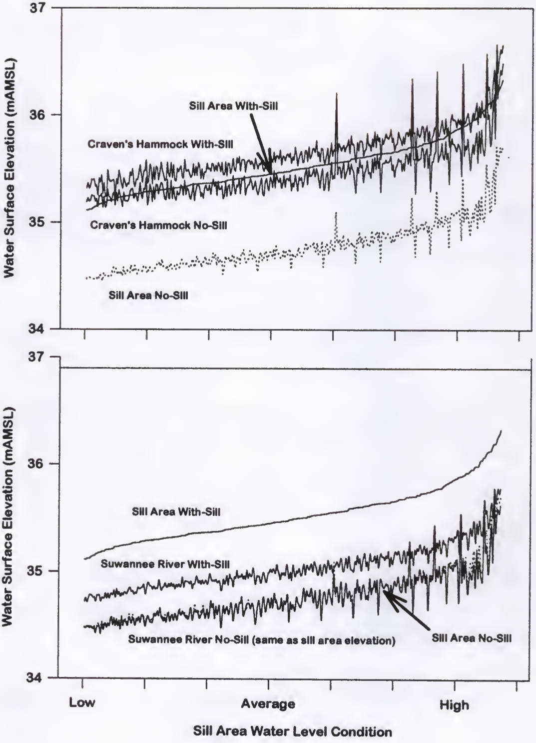


Figure 3-19. Comparison of semi-monthly water surface elevations at recorder stations and the sill gate area during 1983-1993, in "with-sill" and "no-sill" model simulations. Data are arranged to illustrate the change in water levels at the selected station, relative to increasing water depth at the sill.



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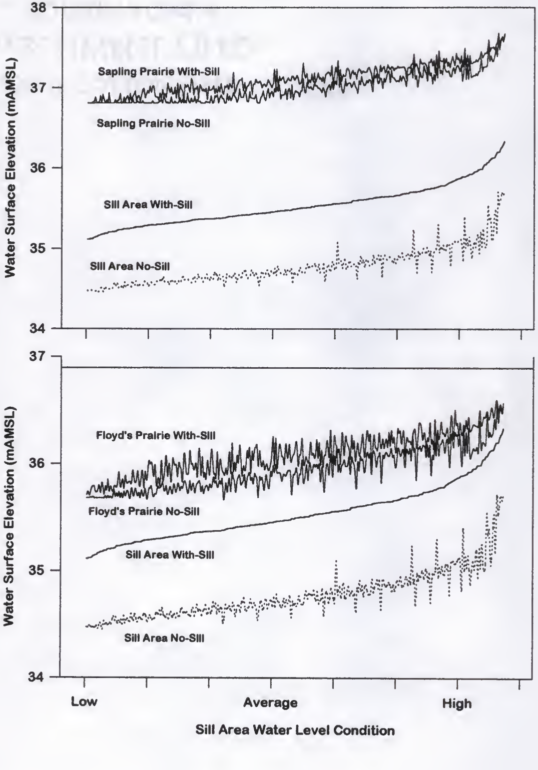

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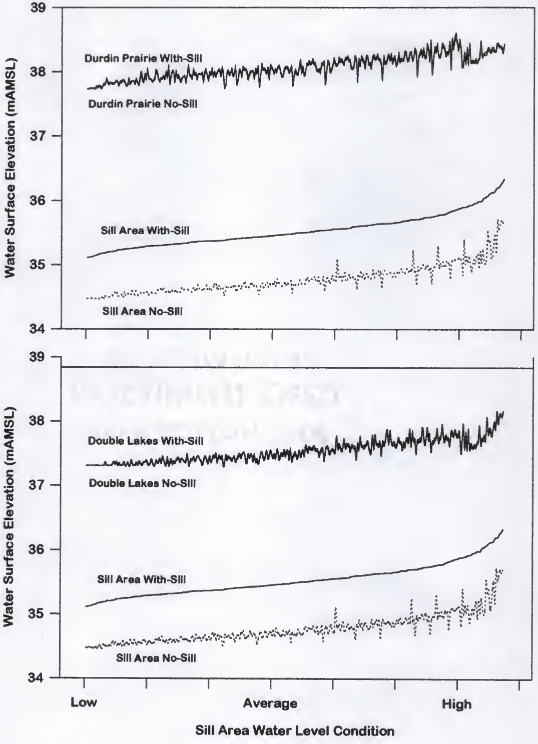

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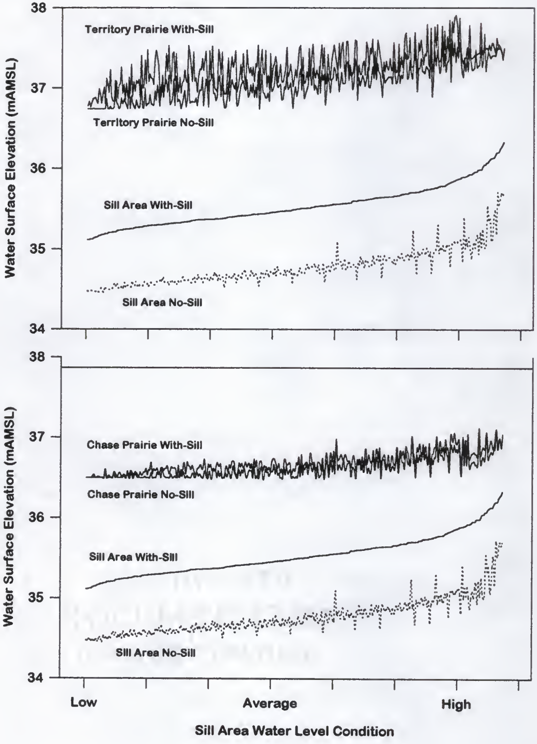

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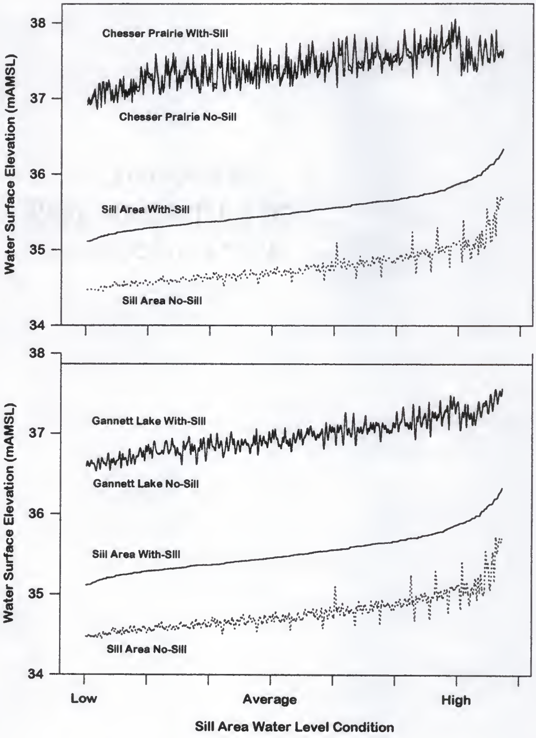

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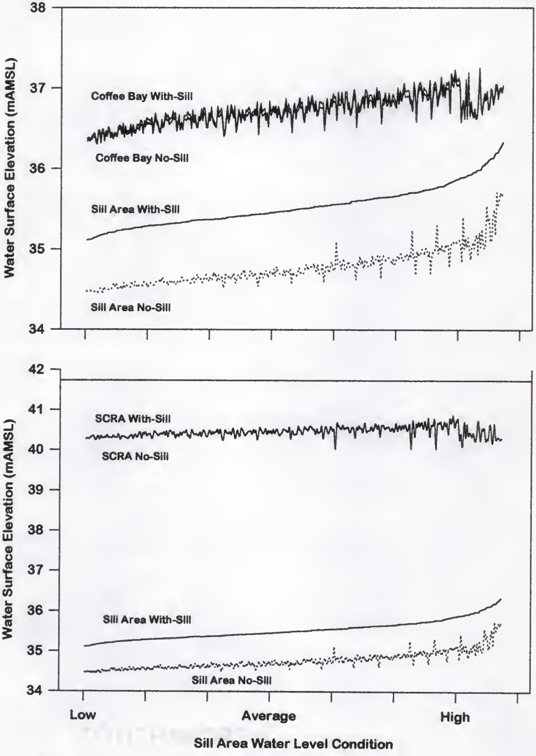

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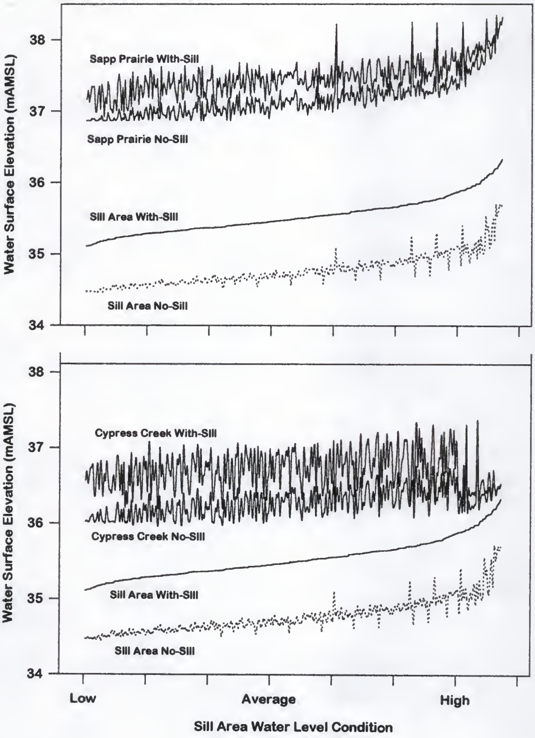

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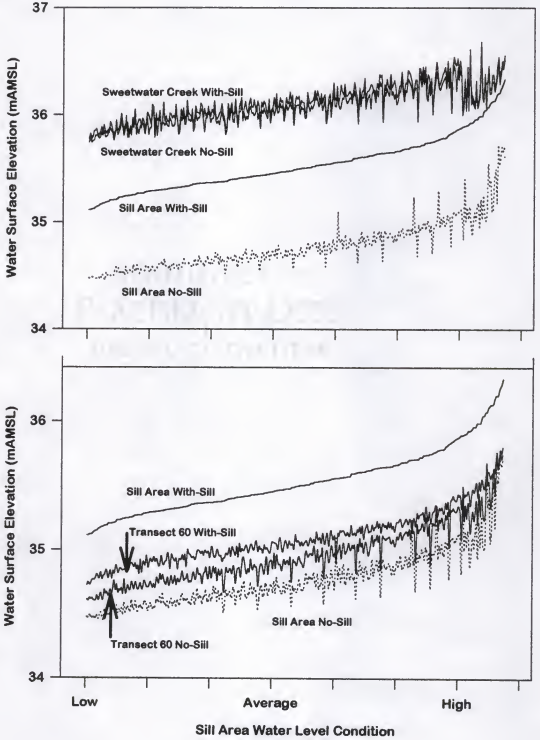

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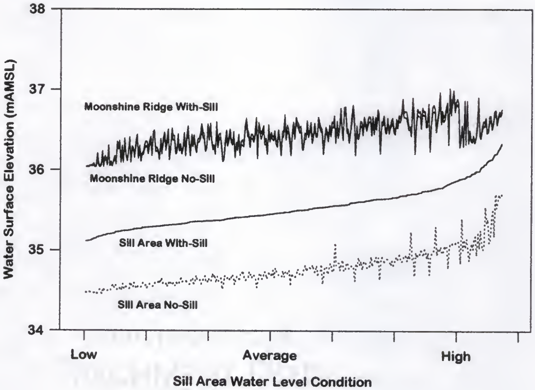

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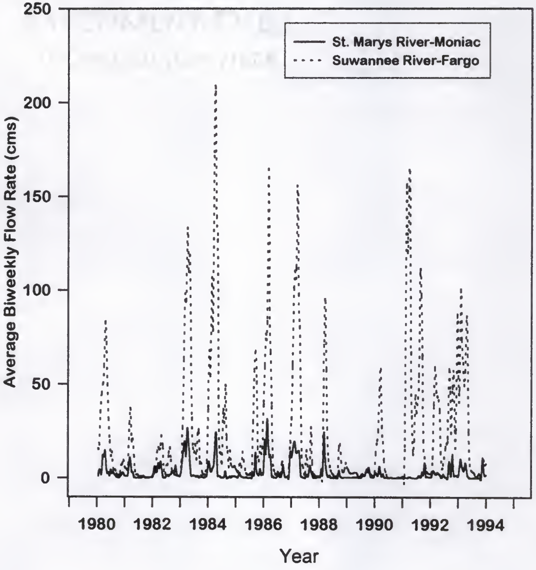


Figure 3-20. Estimated average biweekly flow rates at Suwannee River (Fargo) and St. Marys River (Moniac) during 1980-1993.

impoundment of the sill and the natural berms in the river floodplain delay de-watering, permitting water to backup into this region during these extreme flood events (Figure 3-21). As in the Cypress Creek drainage and Chesser Prairie-Coffee Bay region, changes in hydraulic head differentials are most likely driving this varying relationship. During average and low water levels, this correlated relationship is absent, regardless of the sill's presence, although the removal of the sill may slightly alter the frequencies of hydroperiods in the deepest classes (Figure 3-15).

Hydroperiod frequencies do not change in the Northeast basin with removal of the sill (Figure 3-18). During average and low water level conditions, water levels are more closely correlated with those at the sill when the sill is present than when it is removed, but this does not effect flooding depth group frequencies and durations (Figure 3-19). During periods of extreme high water, the correlation declines, regardless of the sill's presence.

Frequencies of hydroperiod depth groups significantly decrease 1-2 classes in the southwestern creeks (Sweetwater and Cypress) and Sapp Prairie with sill removal (Figure 3-18), although there is much unaccounted variability in creek water levels during average and low levels (Table 3-6). In Cypress and Sweetwater Creeks water levels decrease with increasing levels at the sill when extreme highs occur, indicating a switch in the hydraulic head (Figure 3-19). In extreme high water events the sill restricts de-watering of the western swamp while the creeks continue to accumulate and drain water from their watersheds. As the creek level falls, the creek-river hydraulic head reverses and the creek outflow is restricted by river flow. When the sill is removed this slope

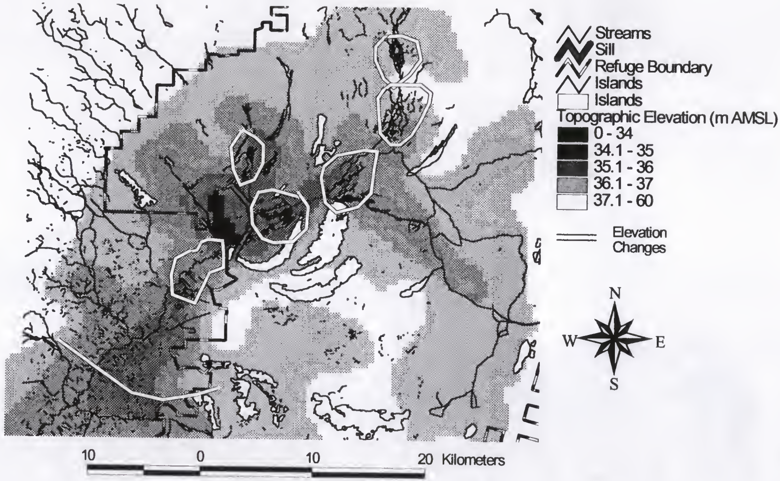


Figure 3-21. Locations of topographic changes in the Suwannee River floodplain within the Okefenokee Swamp and southwest of the Suwannee River sill.

relationship becomes nonsignificant, suggesting that without the sill, de-watering of the swamp through the river supersedes that from the creeks at high water levels, resulting in delayed drainage of the southwestern basin (Table 3-8). A berm in the Suwannee River southwest of Cypress Creek slows the river drainage even in the sill's absence, creating a backwater impoundment in the Cypress Creek basin out of the recorder's range. Levels in Sapp Prairie do not reflect the switch in hydraulic head that occurs in the Cypress Creek basin, although a slight decline in water surface elevation occurs in the "no-sill" simulation (Figure 3-19).

System Sensitivities

The model was also manipulated to increase the volume of water impounded by the sill; all water exiting the swamp in the Suwannee River was retained in the swamp by setting the "Suwannee River outflow coefficient" to 0 for each decade interval (Figure 3-4). This approximated the maximum possible impounded volume, and indicated the largest area that would have been affected with the current sill configuration, historic inflow, precipitation and evaporation, and no river outflow. The area bordered by Craven's Hammock, Billy's Lake, and Transect 60 increased 1-1.5 m due to the reduced outflow; Floyd's Prairie and Coffee Bay increased roughly 0.40 m and no change occurred at Sapling to Chase Prairies and beyond (Figure 3-22). These increased water depths were similarly observed during all decades. Inundation intervals were also prolonged where the increased depths occurred, with most intervals at depths >1.0 m (Figure 3-18). Water levels decreased in the Cypress Creek and Sapp Prairie regions

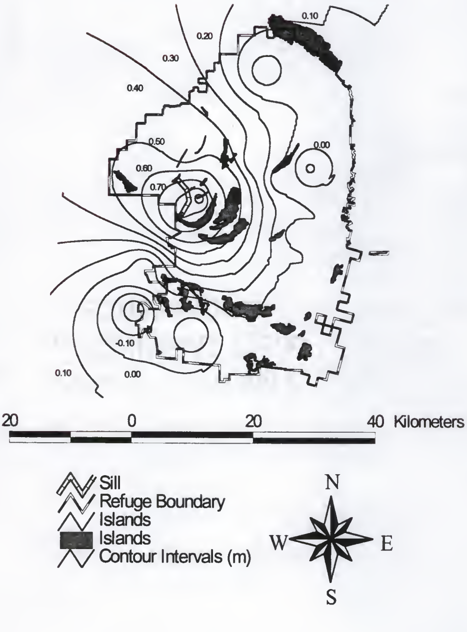


Figure 3-22. Inverse-distance-weighted, contoured estimates of increases in average semi-monthly water surface elevations (m) at recording stations, attributed to Suwannee River outflow retained in the swamp during 1980-1993 model simulations.

with this manipulation during 1941-1949 and 1960-1993 (Figure 3-18). Outflow in these areas may have accelerated as the hydraulic head between the Suwannee River floodplain and the Cypress Creek watershed increased with reduced river flow volumes. However, low water levels in the Cypress Creek drainage during 1950-1959 reduced this hydraulic head difference between Sapp Prairie, Cypress Creek and the Suwannee River floodplain, and hydroperiod group frequencies were not different from those occurring with normal river outflow.

Manipulations of evapotranspiration (ET) rates to examine potential effects of vegetation change on swamp water levels indicate that regional differences exist in the importance of this process to the swamp hydrology. ET was decreased during 1980-1993 to 75% and increased to 150% of estimated volumes with river flow rates set at best "with-sill" model conditions (Suwannee River outflow coefficient=0.15). Changes in ET volumes had greatest effect in the eastern and central swamp; water surface elevations dropped below "no-sill" levels at 150% ET and exceeded "no outflow" levels at 75% ET. Changes in the water surface elevations in the western swamp were less extreme, approaching "no-sill" levels at 150% ET and "no outflow" levels at 75% ET (Figure 3-23). These responses contrast those resulting from outflow volume manipulations. Western swamp water levels fluctuate with changes in outflow proportions, whereas the eastern and central regions remain relatively stable. Regional differences in vegetation distributions and topographic relief drive these responses. The greater topographic gradient in the river floodplain emphasizes changes in outflow volumes in the western swamp, and the prevalence of open water, aquatic and herbaceous prairie, and the low

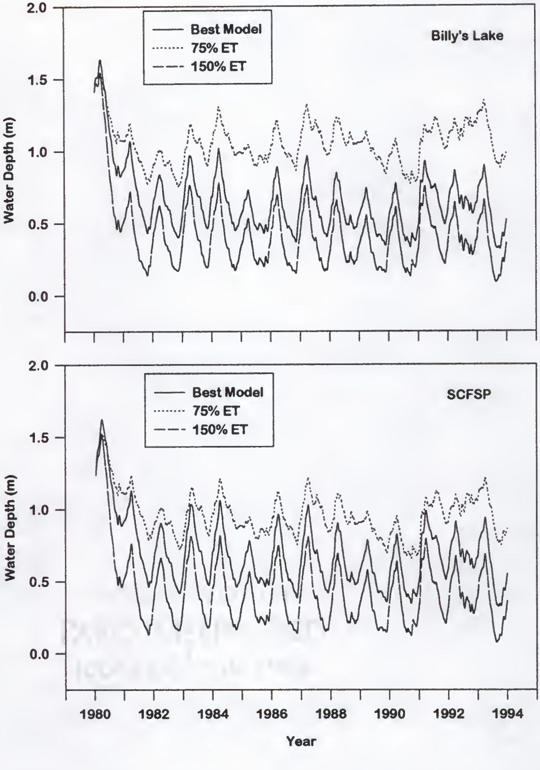
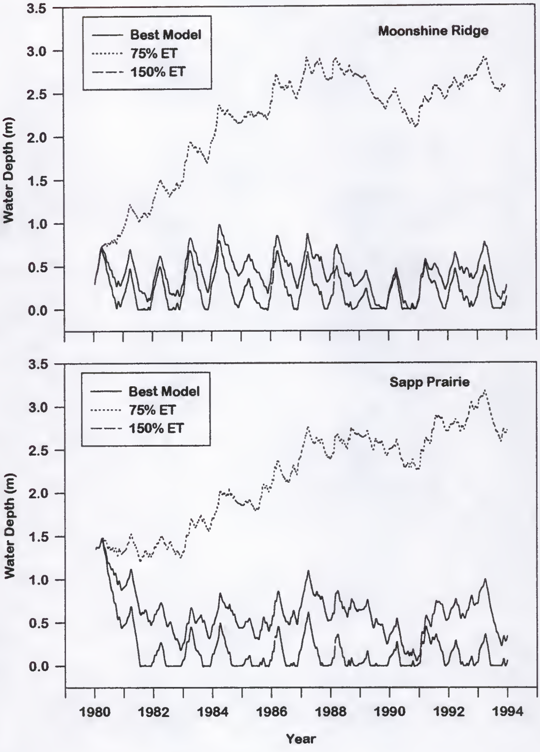


Figure 3-23. Manipulations of estimated evapotranspiration rates and responses of the model at recorder stations during 1980-1993.



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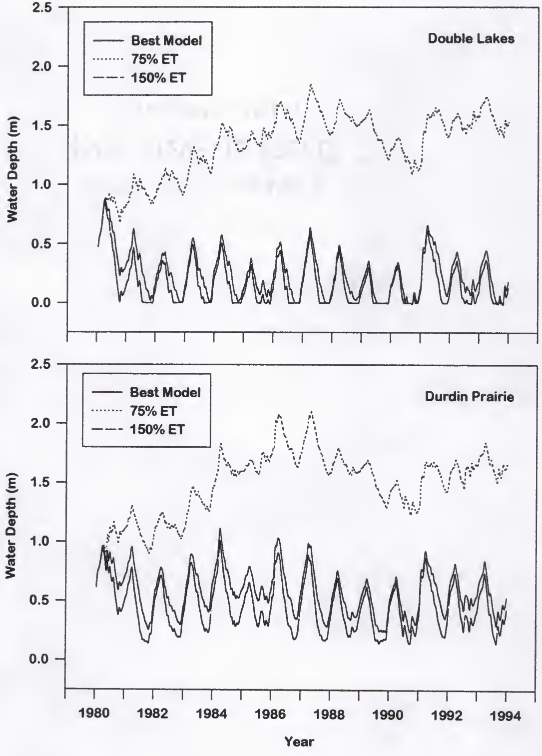

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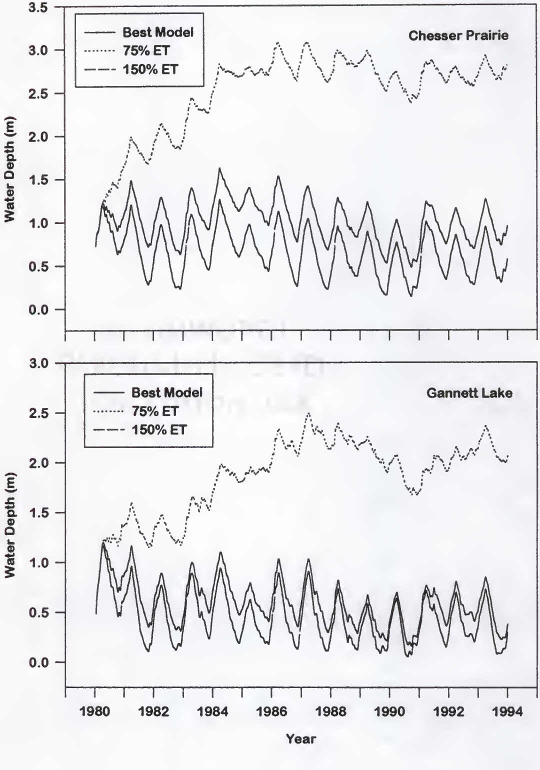

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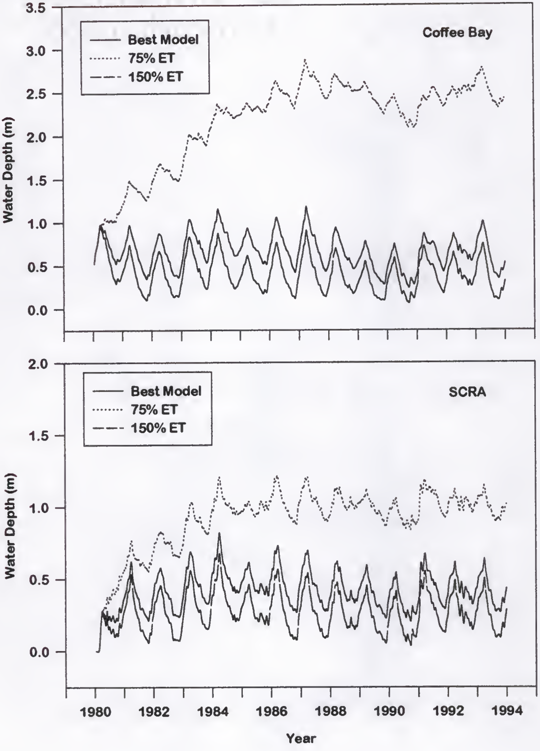

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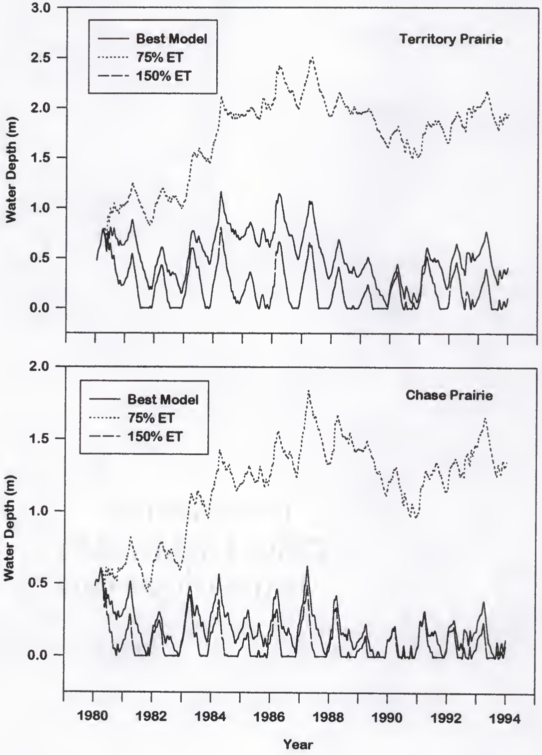

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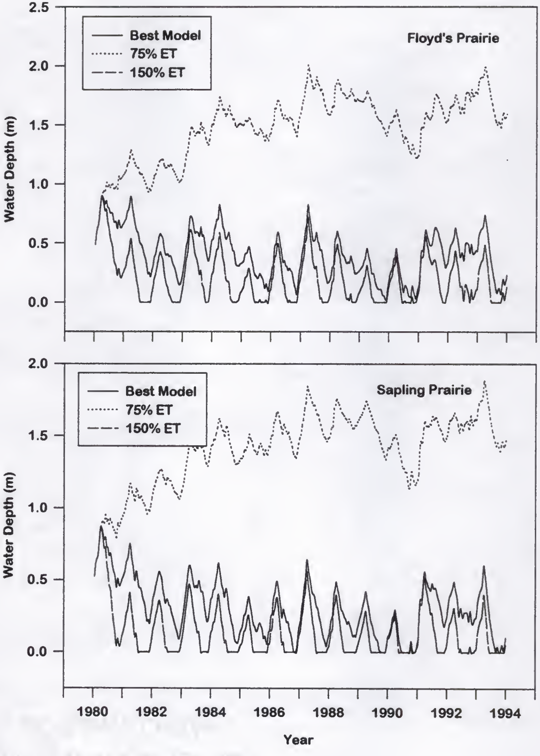

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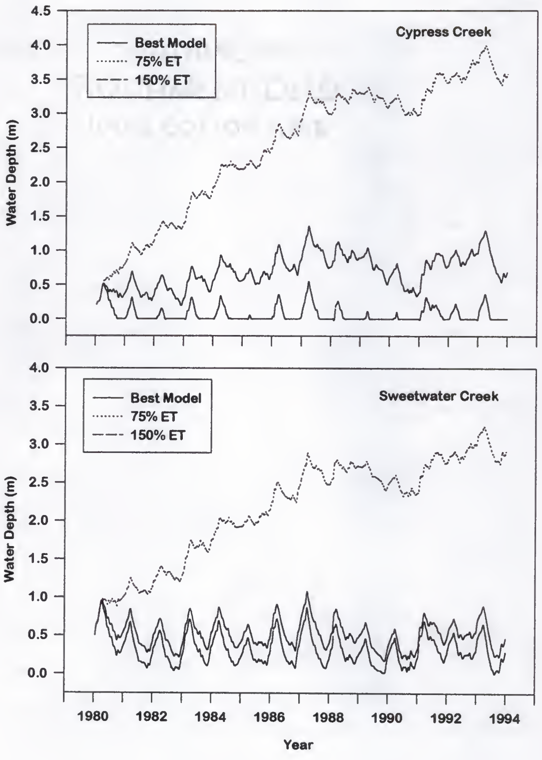

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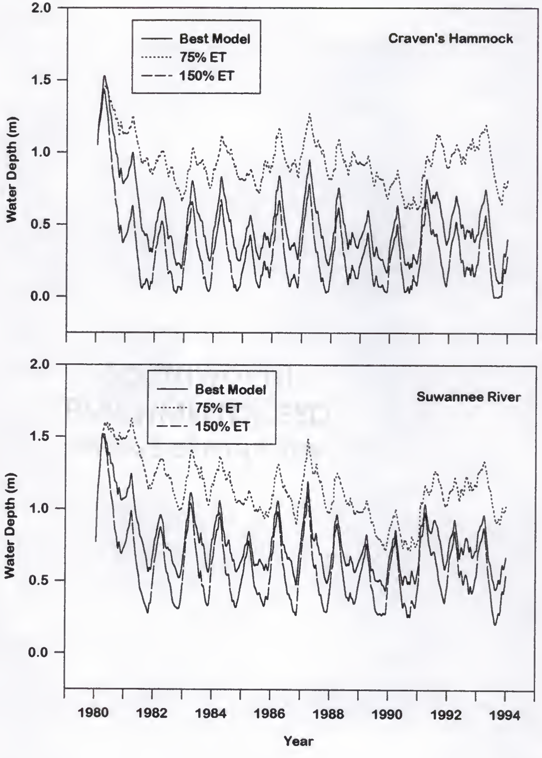

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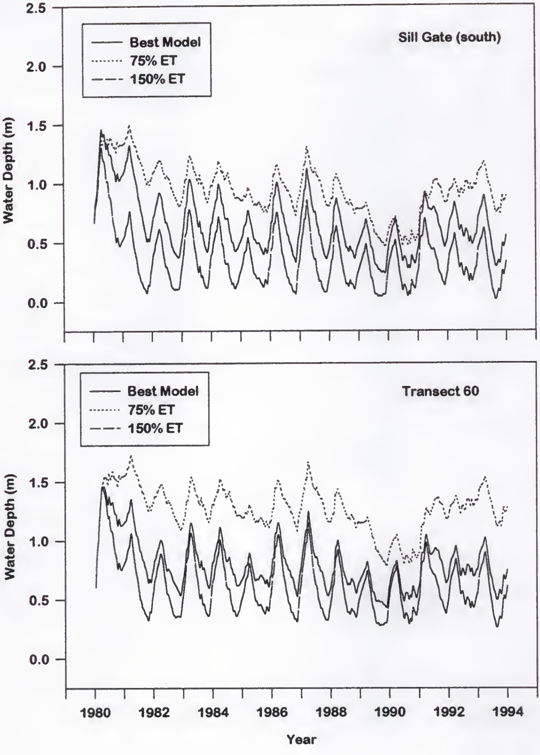


Figure 3-23--continued.

topographic gradient are probably responsible for the importance of ET in the water budget in the remainder of the swamp.

Wildfire Occurrence

The Suwannee River sill was constructed to eliminate or arrest wildfires in the Okefenokee Swamp (Chapter 742, Public Law 81-810, 70 Statute 668). During 1960-1993 wildfires continued to burn throughout the swamp and in the area impounded by the sill (see Chapter 5). Burned area decreased after sill construction, although this decrease was probably not due to the sill since water levels were low or at drought levels when most of the fires were ignited, and the fires occurred outside of the low-water and drought impoundment areas (Figure 3-24). The decrease was more likely due to fire suppression efforts, and the absence of severe drought during 1960-1993 (see Chapter 5). More fires were reported in the Okefenokee Swamp during the with-sill period (151) than during the century prior (98) to its construction. Since 1855, 37 fires were reported in the area affected by the sill impoundment; 18 of these fires were prior to sill construction, and 11 were in the Cypress Creek watershed (see Chapter 5). All of the fires occurring after 1960 were extinguished by fire suppression efforts or precipitation; none were arrested by the sill impoundment. Water levels were at low or drought levels when 16 of the "with-sill" fires occurred. These fires were burning outside the region impounded at low water levels, and probably would have been ignited and burned if the sill had not been present. They would have been arrested by the sill only if they burned into the low-water impoundment area.

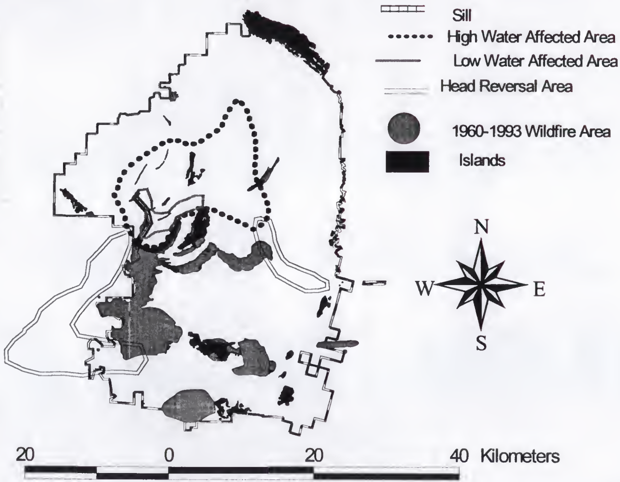


Figure 3-24. Areas affected by the Suwannee River sill at various water level conditions, and burned by wildfires during 1960-1993.

Fire exclusion throughout the swamp will never be achieved with the present sill because of its limited impact area (15% of the swamp at high water levels) and seasonality of impoundment. The sill increases water levels at high and low water conditions in the area encompassed by Transect 60 to Craven's Hammock to Floyd's Prairie to SCFSP (Figure 3-9). Its removal reduces the high water levels in an area slightly larger than its low water level impact area (Figure 3-9). Only a slight change in high and low water levels occurs in the Floyd's Prairie to Sapling Prairie region, and no change occurs east of Bugaboo Island with its removal. Most of the wildfires (25) in the sill and Cypress Creek areas have ignited during June-October, when lightning strikes are most common (Chapter 5) and water levels rapidly decline in the absence of precipitation (Chapter 2). Greatest impoundment occurs at high water, usually during winter months, when thunderstorms and lightning activity are infrequent, and water level accumulation occurs at reduced levels of evapotranspiration. Even if all river outflow were captured by the sill, the impoundment would not increase in area (Figure 3-22), although depths would increase in most of the current impact area (Figure 3-21). This greater impoundment volume would reverse the hydraulic head at the Cypress Creek-Suwannee River junction, causing the creek watershed depths to decrease (Figure 3-14). The Cypress Creek to Sapp Prairie areas have experienced increases in high water levels since the sill's construction, although it is not certain that this is directly attributed to the sill's impoundment. Areas between the Cypress Creek watershed and the sill are not affected by the impoundment, suggesting that the cause of this increase is independent of

the sill, and actually attributed to natural impounding occurring in the river floodplain southwest of the swamp (Figure 3-15).

Vegetation Change

Types of vegetation changes occurring in the sill impoundment area and Cypress Creek watershed mirror those in the remainder of the swamp, although change rates differ (Table 3-9). Wet forest initially increased in the river floodplain impact area during 1952-1977, and was persistent during the next 13 years, whereas shrub, prairie, and upland pine coverages were nearly halved during 1952-1990 (Table 3-10). These changes occurred at rates slower than the surrounding swamp during 1952-1977, and then greater than the surrounding swamp during 1977-1990 (Table 3-11). Shrubs flooded during the initial impoundment did not survive unless located on elevated surfaces. The apparent increase in proportion of forested area was probably due to this decline in shrub coverage. Recruitment of trees and shrubs has been eliminated during the extended flooding; only periods of drought provide exposed surfaces for germination, and survival of seedlings is jeopardized by flooding occurring before sufficient stature to survive impoundment is achieved. As in the remainder of the swamp the impounded area is advancing in successional sequence in the absence of severe fire (see Chapter 4).

Cypress Creek watershed vegetation has converted from prairie, shrub, and scrub composition to shrub, bay-shrub, cypress-gum-shrub, and other wet forest-shrub associations. Most of the prairie coverage in the watershed was eliminated during 1952-1990 (Table 3-10). In contrast to the remainder of the swamp, most of this change

Table 3-9. Vegetation changes occurring in areas affected by the sill and burned during 1855-1993.

Affected Area and Burn Interval	Vegetation Map Date	Vegetation Type	Proportion of Affected Area that Burned	Proportion of Affected Area Unburned	Total Burned Area (ha)	Total Unburned Area (ha)
Cypress Creek Affected Area						
1855 - February 1952	Pre-logging	Cypress-Gum-Shrubs	80.1	62.4	1948	3257
		Briar-Shrubs	19.9	30.3		
	1952	Wetland Forest	60.3	63.0	974	744
		Shrubs	29.0	32.9		
		Prairie	9.9	3.6		
March 1952 - December 1955	Pre-logging	Cypress-Gum-Shrubs	69.0	97.4	5195	152
		Briar-Shrubs	26.5	0		
		Wetland Pine	0	2.6		
	1952	Wetland Forest	60.9	100.0	1736	0.03
		Shrubs	31.0	0		
		Prairie	7.1	0		
	1977	Scrub	15.5	52.6	5147	1
		Shrub	11.4	0		
		Shrub-Cypress	12.4	0		
		Shrub-Bay	6.4	0		
		Shrub-Prairie	35.7	0		
		Upland Pine	0	41.6		

Table 3-9--continued.

Affected Area and Burn Interval	Vegetation Map Date	Vegetation Type	Proportion of Affected Area that Burned	Proportion of Affected Area Unburned	Total Burned Area (ha)	Total Unburned Area (ha)
	1990	Cypress-Gum-Shrubs	32.1	18.9	5195	1
		Mixed Wetland Pine	10.1	9.5		
		Bay-Shrub	37.6	24.3		
		Shrubs	7.5	0		
		Sedges-Ferns-Water Lilies	6.0	0		
		Dense Pine	0	20.3		
		Upland Pine	0	17.6		
March 1952 - October 1977	Pre-logging	Cypress-Gum-Shrubs	69.5	0	1696	0
		Briar-Shrubs	30.5	0		
	1952	Wetland Forest	16.0	0	125	0
		Shrubs	12.7	0		
		Prairie	71.4	0		
	1977	Shrub-Prairie	81.8	0	1696	0
		Shrubs	15.2	0		
November 1977 - 11 May 1990	1977	Shrubs	0	11.6	12	5016
		Scrub	100.0	14.2		
		Scrub/Shrub	0	7.6		
		Shrub-Bay	0	5.8		
		Shrub-Cypress	0	12.8		
		Shrub-Prairie	0	36.7		

Table 3-9--continued.

Affected Area and Burn Interval	Vegetation Map Date	Vegetation Type	Proportion of Affected Area that Burned	Proportion of Affected Area Unburned	Total Burned Area (ha)	Total Unburned Area (ha)
	1990	Mixed Wetland Pine	45.0	9.9	12	5015
		Cypress-Gum-Shrubs	41.3	32.6		
		Bay-Shrub	6.0	38.6		
		Shrubs	0	7.8		
		Sedges-Ferns-Water Lilies	0	6.2		
12 May 1990 - 1993	1990	Cypress-Gum-Shrubs	36.7	32.5	112	4914
		Bay-Shrub	25.6	38.8		
		Shrubs	15.6	7.6		
		Sedges-Ferns-Water Lilies	9.1	6.1		
		Mixed Wetland Pine	6.5	10.0		
Sill Region Affected Area						
1855 - February 1952	Pre-logging	Gum-Bay-Cypress-Shrubs	13.1	22.8	10443	13153
		Cypress-Gum-Shrubs	72.8	41.0		
		Briar-Shrubs	0	17.4		
	1952	Wetland Forest	41.9	38.6	9494	13122
		Shrubs	48.0	37.6		
		Prairie	0	17.0		

Table 3-9--continued.

Affected Area and Burn Interval	Vegetation Map Date	Vegetation Type	Proportion of Affected Area that Burned	Proportion of Affected Area Unburned	Total Burned Area (ha)	Total Unburned Area (ha)
March 1952 - December 1955	Pre-logging	Gum-Bay-Cypress-Shrubs	18.8	7.9	22944	645
		Cypress-Gum-Shrubs	54.7	69.9		
		Briar-Shrubs	11.1	0		
		Bays	6.9	0		
		Upland Pine	0	22.2		
	1952	Wetland Forest	39.9	41.9	22222	389
		Shrubs	42.6	0		
		Prairie	13.0	29.0		
		Upland Pine	0	19.7		
	1977	Shrub-Bay	16.7	0	22943	418
		Scrub	15.6	0		
		Cypress	6.7	0		
		Mixed Cypress	6.1	7.9		
		Aquatic Prairie	6.9	62.3		
		Shrub-Prairie	7.6	6.2		
		Shrub-Cypress	0	5.5		
	1990	Loblolly-Bay	25.0	29.4	22944	417
		Cypress-Gum-Shrubs	22.9	25.3		
		Bay-Shrub	11.9	29.0		
		Gum-Bay-Cypress-Shrubs	25.8	0		
		Sedges-Ferns-Water Lilies	0	0		

Table 3-9--continued.

Affected Area and Burn Interval	Vegetation Map Date	Vegetation Type	Proportion of Affected Area that Burned	Proportion of Affected Area Unburned	Total Burned Area (ha)	Total Unburned Area (ha)
March 1952 - October 1977	Pre-logging	Cypress-Gum-Shrubs	40.0	87.8	16454	416
		Gum-Bay-Cypress-Shrubs	24.1	12.2		
		Briar-Shrubs	15.4	0		
		Bays	9.7	0		
	1952	Wetland Forest	42.6	23.6	15734	159
		Shrubs	36.5	21.6		
		Prairie	16.8	54.8		
	1977	Shrub-Bay	14.3	0	16454	416
		Shrub-Prairie	9.4	6.2		
		Cypress	9.3	0		
		Cypress-Shrub-Prairie	7.4	0		
		Scrub	8.0	0		
		Aquatic Prairie	7.8	62.4		
		Herbaceous Prairie	6.8	0		
		Mixed Cypress	6.6	7.8		
		Bays	6.1	0		
		Shrub-Cypress	0	5.5		

Table 3-9--continued.

Affected Area and Burn Interval	Vegetation Map Date	Vegetation Type	Proportion of Affected Area that Burned	Proportion of Affected Area Unburned	Total Burned Area (ha)	Total Unburned Area (ha)
November 1977 - 11 May 1990	1977	Scrub	100.0	14.2	12	5016
		Shrub-Prairie	0	36.7		
		Shrub-Cypress	0	12.8		
		Shrub	0	11.6		
		Scrub-Shrub	0	7.6		
		Shrub-Bay	0	5.8		
	1990	Mixed Wetland Pine	45.0	9.9	12	5015
		Cypress-Gum-Shrub	41.3	32.6		
		Bay-Shrub	6.0	38.6		
		Shrubs	0	7.8		
		Sedges-Ferns-Water Lilies	0	6.2		
12 May 1990 - 1993	1990	Cypress-Gum-Shrub	36.7	32.5	112	4914
		Bay-Shrub	25.6	38.8		
		Shrubs	15.6	7.6		
		Sedges-Ferns-Water Lilies	9.1	6.1		
		Mixed Wetland Pine	6.5	10.0		

Table 3-10. Composition of vegetation during 1952, 1977, and 1990 throughout the Okefenokee Swamp, the floodplain sill impoundment impact area, and the Cypress Creek watershed area. All calculations were made with 6-class vegetation maps with a minimum mapping unit of 320 m; comparison areas for the sill area of impact (AOI) are clipped to match the area interpreted from 1952 photography, and reported values are % of the vegetation in each category inside and outside of the sill AOI during the specified interval.

Vegetation Class	Proportion Outside the Sill AOI in 1952	Proportion Inside the Sill AOI in 1952	Proportion Outside the Sill AOI in 1977	Proportion Inside the Sill AOI in 1977	Proportion Outside the Sill AOI in 1990	Proportion Inside the Sill AOI in 1990
Floodplain Area						
Wetland Forest	76.0	24.0	67.7	32.3	69.2	30.8
Shrubs	74.1	25.9	78.4	21.6	84.4	15.6
Prairie	75.4	24.6	75.3	24.7	87.1	12.9
Upland Pine	86.6	13.4	83.1	16.9	93.9	6.1
Bare Ground-Urban	100.0	0	n/a[a]	n/a	2.7	97.3
Open Water	100.0	0	100.0	0	99.9	0.1
Cypress Creek Area						
Wetland Forest	97.0	3.0	97.5	2.5	98.4	1.6
Shrubs	98.8	1.2	97.9	2.1	96.5	3.5

Table 3-10--continued.

Vegetation Class	Proportion Outside the Sill AOI in 1952	Proportion Inside the Sill AOI in 1952	Proportion Outside the Sill AOI in 1977	Proportion Inside the Sill AOI in 1977	Proportion Outside the Sill AOI in 1990	Proportion Inside the Sill AOI in 1990
Prairie	99.1	0.9	99.96	0.04	99.95	0.05
Upland Pine	99.98	0.01	99.6	0.4	99.1	0.9
Bare Ground-Urban	100	0	n/a	n/a	100	0
Open Water	100	0	100	0	100	0

[a] Bare Ground-Urban was not included in the 1977 map, and is assumed to be included in the other classes on that map.

Table 3-11. Rate of change in vegetation composition during 1952-1977 and 1977-1990 throughout the Okefenokee Swamp, the floodplain sill impoundment affected area, and Cypress Creek watershed area. All comparisons are made with 6-class vegetation maps with a minimum mapping unit of 320 m; comparison areas for the sill area of impact (AOI) are clipped to match the area interpreted from 1952 photography, and reported values are % of the vegetation category change occurring in the specified interval. *Overall Change* refers to that occurring in the entire swamp, including the sill AOI, during that interval. Bare ground-Urban and Open Water classes were not interpreted in the 1977 map, and are omitted from these comparisons.

Vegetation Class	1952-1977 Change Occurring Outside the Sill AOI	1952-1977 Change Occurring Inside the Sill AOI	1952-1977 Overall Change	1977-1990 Change Occurring Outside the Sill AOI	1977-1990 Change Occurring Inside the Sill AOI	1977-1990 Overall Change
Floodplain Area						
Wetland Forest	30.0	2.1	22.8	70.0	97.9	77.2
Shrubs	8.8	4.0	26.0	91.2	96.0	74.0
Prairie	40.5	21.4	33.2	59.5	78.6	66.8
Upland Pine	94.8	9.8	78.7	5.2	90.2	21.3
Cypress Creek Area						
Wetland Forest	22.1	61.5	22.8	77.9	38.5	77.2
Shrubs	25.0	69.7	26.0	75.0	30.3	74.0
Prairie	31.9	99.1	33.2	68.1	0.9	66.8

Table 3-11--continued.

Vegetation Class	1952-1977 Change Occurring Outside the Sill AOI	1952-1977 Change Occurring Inside the Sill AOI	1952-1977 Overall Change	1977-1990 Change Occurring Outside the Sill AOI	1977-1990 Change Occurring Inside the Sill AOI	1977-1990 Overall Change
Upland Pine	78.2	47.6	78.7	21.8	52.4	21.3

occurred during 1952-1977, and at a slower rate during 1977-1990 (Table 3-11). The fires of 1954-1955 were probably responsible for some of the change from wet forest to shrub and prairie; these areas were rapidly re-vegetated with shrub-prairie and scrub associations by 1977 and wet forest-shrub types by 1990 (Table 3-9). Fires occurring in this area during the past century appear to temporarily arrest forward succession of vegetation, but in the absence of repeated, severe fire, recovery quickly occurs. The sill may actually accelerate drainage of this area during extremely high water levels by reversing the hydraulic head near the creek-river junction. This difference decreases as water levels drop (see Regional Hydrologic Trends). However, the sill does not stop fires in this area of the swamp. Fire activity in the southern third of the swamp has exceeded that in the remainder of the swamp during the "with-sill" period (see Chapter 5).

Discussion

Model Performance

The Okefenokee Swamp hydrologic environment is well-represented by HYDRO-MODEL. Although some discrepancies among modeled and recorded data exist, the model scale is sufficiently detailed to permit assessment of the effects of the Suwannee River Sill on the Okefenokee Swamp landscape. In most cases localized failure of the model can be attributed to specific model or data features. The model processing area is the Okefenokee Swamp National Wildlife Refuge boundary and the Suwannee River floodplain to Echols County, GA; this limit was required by computing constraints and

project objectives. Features that may affect hydrologic processes in the swamp, such as watersheds of the northwestern streams, topographic relief beyond the eastern perimeter, and seepage flows along the eastern rim, were eliminated by this boundary. If the processing boundary had been extended beyond the refuge boundary, these features would have had an opportunity to influence swamp hydrology, which might have improved model performance in these areas. However, additional processing power, memory, and storage space would be required to model a larger area.

Error can also be attributed to model processing scale, which was limited to 500x500 m grid cells. Smaller scale would have improved local accuracies, but would have increased processing time and storage space exponentially. In most cases the model output agreed with interpolated check station data, which generalized local variability to the model scale. Scale errors occurred primarily where check station locations did not represent the general local environment. For example where recorder stations were located in ditches or holes, modeled water depth estimates were low because the grid-cells of the model topography did not represent the depression at the small scale. Areas of the swamp could be subset to create smaller regions for model processing, and these could be gridded at a smaller cell size. The smaller cell size would permit more local landscape detail. Re-sampling swamp topographic elevations at the smaller scale would be necessary, however, to provide data for a more resolute topographic surface for local models.

Several assumptions were made in designing the model and creating the model data grids. As mentioned above, the swamp topographic surface was approximated with

data collected at a variable scale and interpolated to 250,000 m^2 grid cells. Local variability is lost at this scale, but hydrology at the landscape level is represented with sufficient accuracy. Other data used in the model were also interpolated from stations scattered throughout the area. Precipitation was represented by data interpolated from 22 stations and totaled over semi-monthly intervals. As discussed in chapter 2, these data were at sufficient temporal and spatial density to accurately represent the area rainfall variability, so that model error is probably not attributable to precipitation estimates. In fact, 14 stations would have adequately represented area precipitation variability for semi-monthly estimates of daily precipitation (Chapter 2). Evapotranspiration rates were also estimated from interpolated point data that had been totaled monthly and then halved to approximate semi-monthly ET. These values were estimated using Thornthwaite's approximation of potential evapotranspiration, which has been reported to be a low estimate (M. Focazio, USGS unpublished data), although Yin and Brook (1992a) believed it was the best estimator of actual evapotranspiration in the Okefenokee Swamp when compared to Blaney-Criddle and Holdridge PET estimation methods. The model's ET adjustment of 25% approached the estimates of Thornthwaite's deficiency of 30-40%. If model error is attributed to ET estimates, this probably is important primarily in the eastern swamp, where ET plays a greater role in directing water level fluctuations than in the western swamp. ET rates were also adjusted with a proportional multiplier to account for differences in local vegetation type. This modifier could be improved by species-specific ET rates instead of those for structural types (tree, shrub, prairie, open water); these values were not available when the model was constructed, but could be

incorporated in future model manipulations. Inflow and outflow volumes were also a source of error. They were estimated from measured flow rates and linear regression relationships between creeks and rivers. More accurate volumes could be estimated with a longer flow database that includes a greater range of water level conditions at more inflow and outflow locations. Additional recorder stations are also needed in the seepage flows along the eastern swamp perimeter to assess connectivity to swamp and upland water level fluctuations.

Groundwater exchange was assumed to be minimal when the model was constructed (Hyatt 1984, Hyatt and Brook 1984, Blood 1981, Rykiel 1977), and the contribution of this component was considered less than the expected model error. Although this may be true from a landscape perspective, this assumption is probably erroneous on a local or basin scale. There is anecdotal evidence of subsurface contribution to the eastern swamp hydrologic environment; springs or upwellings have been reported near Floyd's Island (J. Burkart, pers. comm.) and in southern Chesser Prairie (pers. observ.), and elsewhere in the swamp (Hyatt 1984, Hopkins 1947). The minimal variability of water surface elevations in the Durdin Prairie area may be due to a subsurface contribution. Refining the volume and variability of this input should be a priority of future research on the swamp hydrologic environment, especially in the eastern swamp.

Effects of the Suwannee River Sill

The Suwannee River has elevated water levels and prolonged flooding in approximately 18% of the Okefenokee Swamp. Most (15%) of the impounded area is in the Suwannee River floodplain to the east of the sill; 3% of the impacted area is in the Cypress Creek watershed where the effect may be due to backwater impounded rather than direct flooding by the sill. The actual linkage between the sill and this watershed is uncertain. This watershed is isolated from most of the swamp by landscape topographic features, such as sand-based islands (Blackjack, Honey, Billy's, Strange) and peninsulas (Pocket, Soldier's Camp) surrounding the Cypress Creek-Sapp Prairie area. Sweetwater Creek and Honey Prairie, located to the north and northeast of Cypress Creek and between the sill and Cypress Creek, have not demonstrated any change in water surface elevations or hydroperiod frequencies since sill construction. In addition, the impact exists under all water level conditions, unlike closer areas that are affected primarily at high water levels and less so at average and low water levels. There is a reversal of hydraulic head that occurs in this watershed under extreme high water level conditions that is less frequent and begins at higher water levels in the sill's absence. Removal of the sill creates a change in the river-creek profile. Cypress Creek levels drop below those at the river and drainage slows until the river recedes.

The spatial extent of the sill's impact varies with general water level conditions. At extremely high water levels the area encompassed by Craven's Hammock to Floyd's and Sapling Prairies to the western edge of Chase Prairie to SCFSP and the Sill has

elevated average water levels of a few centimeters to a meter. At extremely high levels water in the eastern swamp (Buck Prairie to Chesser Prairie and south) that usually does not show surface movement may be forced to the east and southeast by the delayed drainage caused by the sill. The result is a head reversal maintained until the water impounded at the sill decreases. During high, average, and low levels, the eastern area shows little surface water movement and no difference in elevations with and without the sill. Water flow becomes apparent west of Coffee Bay as water drains out of southwestern Chase Prairie towards Billy's Island. These conditions probably occurred prior to the Suwannee Canal construction; attempts to drain the swamp towards the Suwannee River would probably not have been made had there not been evidence in the eastern swamp of westward flow, which begins in the region of the canal's westward terminus.

At average and low water surface elevations the area affected by the sill's impoundment decreases. Under these conditions no differences in water surface elevations with sill removal occurred at Coffee Bay, Chase, Territory, Durdin, and Chesser Prairies, Double Lakes, Gannett Lake, Moonshine Ridge, and SCRA. This region is delineated in the surface topography by a rise that is not exceeded by the impounded water. Average water surface levels at Craven's Hammock to Floyd's and south Sapling Prairies to SCFSP decline with removal of the sill, although this drop is small in Floyd's and Sapling Prairies. At extremely low water surface elevations, the sill impounds water only in the riverbed and not in the surrounding floodplain, and it's removal has no effect outside the riverbed.

Even if all water flowing in the Suwannee River at the sill was retained in the swamp, the affected area would not exceed that affected at the highest water levels with outflow. The Craven's Hammock to Floyd's Prairie to western Chase Prairie to Billy's Island area would experience an increase in water surface elevations of 0.05-1.0 m, with greater increase closer to the sill. This affected area follows a topographic contour that would have to be exceeded by the impounded water surface elevation before a larger area of the swamp would be flooded.

Greatest spatial impoundment by the sill occurs during high and extreme high water levels, which usually occur in the winter months when evapotranspiration is minimal and winter frontal systems bring precipitation. This is a period when wildfire frequency is low and lightning ignitions, which are the predominant cause of swamp wildfires, are least frequent (see Chapter 5). If the sill is to provide fire and drought protection, it should be increasing hydroperiods during drier periods when rainfall is minimal and lightning-caused storms are frequent. Because the swamp hydrologic system is so tightly liked with area rainfall and evapotranspiration, however, the sill can not impound enough water during the period when its impoundment effects are most needed to counteract drought and arrest wildfire spread. Even if all out flowing water were captured by the sill, the region impounded under low water conditions would increase minimally. Increasing the affected area to significantly more than 15% of the swamp can only be achieved by increasing area rainfall. This effect occurred during February-March 1998, when record amounts of precipitation fell in the swamp watershed and throughout the swamp, and water levels reached record high levels.

The communities affected by this impoundment are undergoing the same successional changes as those beyond the reach of sill's direct effects, although rates of change were initially faster in the impounded region. Communities in the affected region were in general beyond the stage most effected by increased hydroperiods (germination) when flooded by the impounded water, and are undergoing conversion to shrub-forest and wet forest types. Removal of fire from these areas and the surrounding swamp has facilitated this change, which probably will not be reversed until a widespread, severe and extensive drought is accompanied by a severe fire. Under these conditions the sill will not stop fires from igniting and spreading, and the impounded area will be negligible.

System Sensitivities

Although the Okefenokee Swamp can be described as a "bowl in the landscape", there is diversity in the landscape that creates a spatially variable hydrologic environment that does not react uniformly to system perturbations. In this study five basins were delineated where hydrologic fluctuations follow general trends in seasonal weather patterns but levels of variability differ (Figures 2-11 and 2-12). Sensitivities to manipulations of components in the water budget and landscape vary with the basin. The eastern swamp basins quickly respond to changes in evapotranspiration rates, whereas the western basin shows less sensitivity to this parameter. More disruption to the western hydrologic environment occurs when semi-monthly outflow or inflow proportions are adjusted. These responses reflect features in the swamp landscape. The western swamp

is in the Suwannee River floodplain, and receives more throughput, with inflow from northwestern creeks and outflow in the Suwannee River. Evapotranspiration rate adjustments affect the volume of water entering this area in peripheral regions, but most of the area's water movements are due to river and creek fluctuations, and ET variability is of secondary importance, primarily as it influences the volume of in flowing and out flowing water. Fluctuations in river and creek volumes due to influences outside of the Refuge boundaries have the potential to disrupt the hydrologic environment of this area of the swamp. The eastern swamp contrasts the western swamp's low sensitivity to fluctuations in ET. Throughput is minimal under all but very high water level conditions in the precipitation-evapotranspiration driven eastern swamp. Small changes in ET in the eastern swamp cause large changes in water levels. In reality these changes could be caused by altered standing water volumes due to draining or flooding, or changes in vegetation coverage. It is possible that the small fluctuations in annual water levels of the northeastern basin are directed by species-specific ET rates; a change in vegetation coverage due to small alterations in water levels could result in species conversions in this area of high diversity as species-specific ET rates also change.

The Okefenokee Swamp has a history of hydrologic manipulation. Although currently the most visible disruption, the Suwannee River sill has had limited impacts on swamp hydrology and vegetation compared to other manipulations of the past 100 years. The Suwannee Canal has probably affected flow to the western swamp in the adjacent areas, and may increase de-watering of adjacent prairies under certain conditions, and the canal berms are an interruption in what once was an extensive prairie (Christie to Grand

Prairie). These areas east of Bugaboo Island remain largely hydrologically isolated from the western swamp, however, in spite of the canal. Dredging in the northeast has also affected local hydrologic dynamics, but the extent is limited, which has isolated the impacts to the Kingfisher Landing-North Durdin Prairie region. Although the swamp seems to be recovering structurally from early 20th century logging, species composition may be changing to associations less dependent on fire for maintenance (see Chapter 4). Ultimately the hydrologic environment may change, as ET rates vary with different species, and different vegetation alters surface water flow rates. Perpetuation of fire in the landscape may also change with the predominance of species that do not readily carry fire. These changes are exacerbated by an altered natural wildfire regime, that is manipulated by fire management protocols to limit the severity and extent of fires, particularly in the swamp perimeter where many wildfires are naturally ignited. The intended function of the sill was to assist in these fire control efforts; it does not appear to be achieving this purpose throughout the swamp. However, in combination with the historic perturbations that have variously affected the swamp hydrology and vegetation, the sill is contributing to changes in driving processes that ultimately structure the Okefenokee Swamp landscape.

CHAPTER 4
LANDSCAPE LEVEL VEGETATION CHANGES IN OKEFENOKEE SWAMP

Introduction

Dynamics of Swamp Vegetation

Plant community composition and distribution are the result of dynamic interactions of autogenic (self-imposed) and allogenic (environmentally imposed) factors. The sequence of species occupying a site is determined by the abiotic environmental conditions, interactions among individuals and species (such as competition for resources), and propagule availability. The result on local and landscape scales is not static; as species composition, structure, and site environment change, so do the structure and composition of the landscape, creating a "moving mosaic" of communities in various stages of development, responding to disturbances with which they evolved. Responses to these events may be fairly predictable; this predictability in response to change is due to the regularity of the types and intensities of disturbances or driving functions occurring throughout the system's history. Disruption of the relationships of community components and processes may alter the responses of

individuals, species, and communities. A change in the composition, structure, and dynamics of the landscape may ultimately result.

Vegetation communities generally undergo a predictable sequence of change in Okefenokee Swamp, determined primarily by site hydrology and fire history (Deuver 1984a, 1984b, 1983, 1982, 1979, Hamilton 1984, 1982, Cypert 1973, 1972, 1961). Longest hydroperiods and deepest water levels are tolerated by species in areas of open water and aquatic prairie (e.g., spatterdock, *Nuphar luteum*; fragrant water lily, *Nymphaea odorata*; golden club, *Orontium aquaticum*). Shallower water depths and more frequent exposure characterize herbaceous prairie (e.g., Walter's sedge, *Carex walteriana*; yellow-eyed grass, *Xyris* spp.; broomsedge, *Andropogon virginicum;* redroot, *Lacnanthes caroliniana*). As water depths decrease and exposure times increase due to litter accumulation or drought, shrubs invade, with shade intolerant species (e.g., fetterbush, *Leucothoe racemosa*; titi, *Cyrilla racemiflora*) gradually replaced by those more suited to shaded conditions (e.g., hurrahbush, *Lyonia lucida*). Forest species tolerant of longer hydroperiods and deeper water are cypress and blackgum, which may eventually be displaced by bays as ground surface rises due to litter accumulation, and shade creates less favorable conditions for cypress and blackgum regeneration. Depending on the burn intensity, fire can disrupt this progression and reset the community to an earlier stage, or retard the cycle by pruning above-ground growth, without changing dominant species composition (Hamilton 1984, 1982) (Figure 4-1). Evidence of these cycles exist in the peat throughout the swamp where community

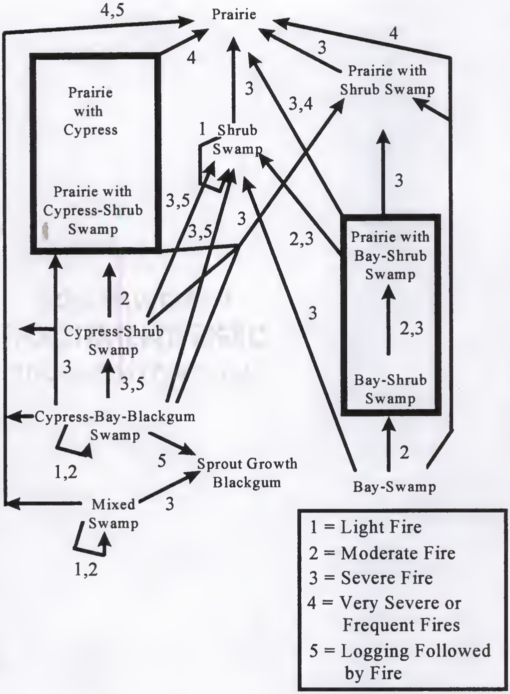


Figure 4-1. General effects of fire and logging disturbances on Okefenokee Swamp vegetation types, adapted from Hamilton (1982).

succession checked by fire has resulted in a perpetually changing landscape since the swamp's most recent peat accumulation began 6,500 years ago (Cohen 1975, 1973b, Cohen et al. 1984).

Most of the Okefenokee Swamp has been affected during the past century by some type of man-induced manipulation, including logging (1890-1942), ditching (1890-1900), peat mining (1930s-early 1950s), alteration of fire regime (1937-present), canoe trail maintenance including trimming and dredging (1937-present), and impoundment (1960-present) (Trowell 1989c). The spatial and temporal effects and permanence of these modifications are uncertain. Not only is community composition directly altered by these processes, but the subsequent responses of the landscape to these disturbances is also affected by the change in species composition. Predictions of responses to future disturbances, either "natural" such as wildfire and drought, or "unnatural" such as impoundment, draining, or modified fire regime, are less certain following these artificial disturbances. Hamilton (1984, 1982) documented Okefenokee Swamp vegetation composition in 1977 following the turn of the century logging and Suwannee Canal construction, peat mining of the 1940s, and Suwannee River Sill construction in 1960. He proposed sequences of changes observed due to these factors (Figure 4-1), and expected succession in the absence of these disturbances and with various hydropatterns (Figure 4-2). He did not propose a time line for these changes, since the frequency of these disturbances and the system's response had not been examined over a sufficient period. The availability of GIS permits a spatial comparison of the disturbances and the

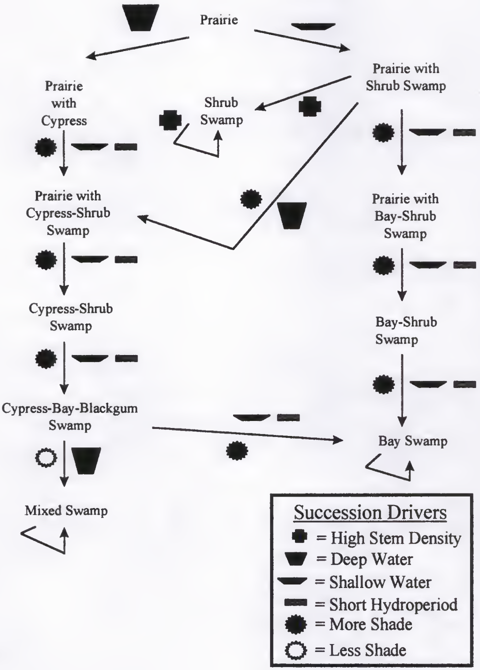


Figure 4-2. Autogenic succession and conditions that drive succession in the Okefenokee Swamp, adapted from Hamilton (1982).

system's response during the century since the initial logging occurred. The recent periodicity of the resulting changes might be elucidated with this type of spatial and temporal analysis.

Sill Affected Vegetation Change

In addition to questions of the Suwannee River Sill's effects on the Okefenokee Swamp hydrology addressed in Chapter 3 are questions of its effects on the swamp vegetation composition and distribution. Changes in swamp vegetation since the sill was constructed can not be attributed directly to the sill without also examining vegetation responses to these other disturbances, within and outside of the area hydrologically affected by the sill. This chapter examines swamp vegetation landscape composition and community distributions in the Okefenokee Swamp prior to logging (1850-1890), prior to the wildfires of 1954-1955 and sill construction (1952), and 17 (1977) and 30 (1990) years following sill construction. These intervals were selected due to data availability , as well as timing of fire, logging, and sill construction. My objectives were to identify the types and locations of vegetation change occurring in the swamp during these intervals, determine the roles of various disturbance types (such as fire, logging, and impoundment) in directing the changes occurring in the swamp landscape, and assign a temporal scale to these changes.

Methods

Logging Tramlines

Most of the marketable timber (including slash pine, *Pinus elliottii*; longleaf pine, *P. palustris*; pond pine, *P. serotina*; pond cypress, *Taxodium ascendens*; sweet bay, *Magnolia virginiana*; swamp blackgum, *Nyssa sylvatica* v. *biflora;* loblolly bay, *Gordonia lasianthus)* was removed from Okefenokee Swamp during 1890-1942 along railways (tramlines) constructed to transport timber from the swamp interior; where the peat surface was inundated, the rails were elevated on pilings above the water surface (Trowell 1994, 1984b, 1983, Izlar 1984). Most harvesting occurred within 100-300 m of the tramlines (Trowell 1994, 1984b). Although the railways were dismantled following timber removal, evidence of the harvest remains, including landscape-level scarring in the vegetation structure and bases of pilings exposed during low water periods. Trowell (1994, 1983) compiled a map of tramline locations throughout the swamp using logging company records, aerial photographs, and survey notes. This logging tramline map was not georeferenced to a coordinate system; in order to compare vegetation, fire, and hydrologic history between logged and unlogged areas, the tramline map needed to be referenced to a coordinate system common among the maps. To create the geo-referenced tramline map, historic logging rails were extracted with ARCINFO (version 7.0, ESRI, Inc., Redlands, CA 92373) from USGS 1:100,000 Digital Line Graph (DLG) coverages from 1994, and the resulting coverage was checked against 1994 USGS

1:24,000 quadrangle maps for missing and mislabeled logging rails. Missing rails were digitized from paper USGS 1:24,000 maps and merged with the logging rails derived from the DLG coverage. Trowell's 1994 map, "Logging Railroads in the Okefenokee Swamp (1889-1942)", was photo reduced to 8.5x11 inches and scanned at 300 dots per inch on a flatbed scanner. The reduced, scanned map was georeferenced to the tramlines compiled from the USGS map. An *affine* transformation was used with 8 control points to match the maps. The *affine* transformation function is

$$x' = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{y} + \mathbf{C}$$

$$y' = \mathbf{D}\mathbf{x} + \mathbf{E}\mathbf{y} + \mathbf{F}$$

where **x** and **y** are coordinates of the input coverage (the original tramline map) and x' and y' are coordinates of the output coverage (the USGS map). A, B, C, D, E, and F are computed by comparing the differences in positions and locations of the control points between the maps. The control points are scaled, translated, and rotated between maps to achieve the match (ESRI 1992), and the functions are then applied throughout the map to complete the transformation. A root mean square error (RMS) of 150 m was declared acceptable; this was at least as accurate as the original tramline map. Control points were reselected until this accuracy was achieved. Artifacts such as text scanned from the original map were removed before the scanned, raster version was vectorized. Breaks in logging lines, errors introduced in the transformation process, or missing lines were corrected using the following decision rule sequence:

1) The USGS logging tramline information was believed to be planimetrically accurate, but less quantitatively accurate than Trowell's original tramline map.

Therefore, if the original logging tramline map indicated a railway, that feature was included in the digital map. If the feature was mapped by USGS, the USGS feature was retained and the original map feature was removed, since in the transformation its position was less accurate than the USGS feature position.

2) If a tramline was present on the original tramline map and not on the USGS map, the tramline information was checked against historic photographs (1952) and satellite imagery (1990) to locate existing large-scale marks in the vegetation, so the location could be placed on the digital map. The missing tramlines were digitized using scars (large-scale marks in the vegetation where recovery from logging was occurring) visible from these sources as guides.

3) Where features existed on both USGS and original tramline maps, but locational discrepancies occurred, the logging tramlines derived from the original map were adjusted to the position indicated in the USGS map.

Tramline locations in the final composite map were estimated to be within 400 m of their true location. This map became the base map, composited with island, stream, and river vectors, for compiling the pre-logging vegetation map of the swamp.

The final tramline vector map (or arc coverage) was converted to several grids representing logged and unlogged areas. A buffer was used around the logging tramline arcs to represent the logged and unlogged areas separately (Figure 4-3). All areas within 200 m of the logging tramlines were labeled as "logged", and areas beyond this 200 m

Figure 4-3. Locations of logging railroads (tramlines) and buffer used to approximate logged area.

buffer were considered "unlogged". The buffered tramlines were gridded to 10 m, 240 m, and 320 m grid cells using ARCGRID, for comparison with other vegetation maps (see below).

Pre-Logging Vegetation (1850-1890)

The map of logging railways created from the tramline features on the USGS 1994 DLGs and Trowell (1994, 1983) was used as a base map to plot vegetation community distributions along the pre-logging survey routes. Although much of the Okefenokee Swamp was logged during 1890-1942, and the composition of the harvest was estimated by Hopkins (1947) and Izlar (1984), a spatial representation or map of pre-logging vegetation map had never been constructed. An approximation of pre-logging vegetation composition occurring during 1850-1890 was made from notes compiled by Trowell (1994, 1989a, 1989b, 1988a, 1988b, 1984b) of several surveys conducted during 1850-1942 (Table 4-1). Because no detailed maps of vegetation cover were supplied with the summaries of the surveyors' narratives, positions of vegetation types were approximated from the survey descriptions of location, distance covered since last known position, and notes compiled in survey route descriptions by Trowell (1989b). References to landmarks such as streams and rivers, large islands, and large prairies also provided positional information (Figure 4-4). Although there was room for error in this method, there were consistencies among the surveyors' descriptions of areas visited by more than one surveyor, and distance estimates were generally comparable among surveyors. It was assumed that the vegetation currently most likely to be different from

Table 4-1. Sources of pre-logging survey notes used to create the pre-logging vegetation map of Okefenokee Swamp.

Survey Party	Survey Date	Reference
Mansfield Torrence	1850	Trowell (1989)
Pendleton-Haines	1875	Trowell (1989)
Constitution (Clarke, Pendleton, Haines, Little)	1875	Trowell (1989)
Fremont	1878-1879	Trowell (1989)
Roland Harper	1902, 1919	Trowell (1988)
Suwannee Canal Company, Hebard Lumber Company	1890-1937	Trowell (1984)
Various Logging Interests	1895-1942	Trowell (1994)

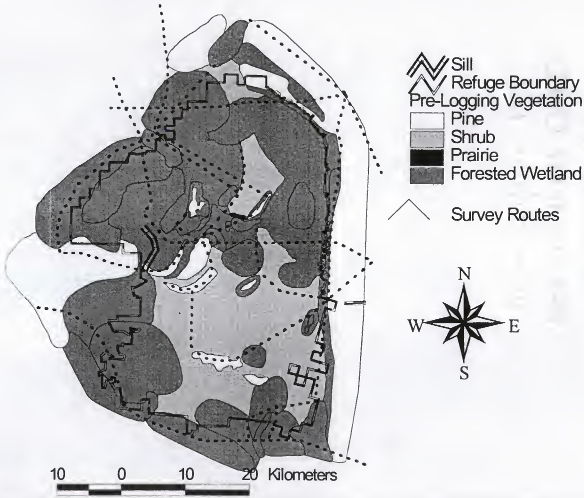


Figure 4-4. Estimated pre-logging (1850-early 1900s) vegetation in Okefenokee Swamp, and approximate routes of 19th and 20th century surveyors.

historical, pre-logging descriptions was where the tramlines, and hence logging, had occurred. However, survey information included areas later logged as well as those never logged, so the final pre-logging map includes all areas described by surveyors. Dates of logging were also noted from Trowell (1994), or references in the survey notes (Trowell 1989a, 1989b, 1988a, 1988b, 1984b) and logging company records (Trowell 1984b). After vegetation descriptions were recorded on the tramline map, they were summarized into 12 classes (Table 4-2). The selection of vegetation class types was determined by the 1990 satellite image classification (see satellite image classification discussion); a common set of classes among vegetation maps was necessary to permit comparisons among maps for change assessment. Boundaries of vegetation communities were estimated on a paper tramline map and screen-digitizing on the tramline coverage to create vegetation polygons (Figure 4-4). The polygons were converted to 10 m grid cells in ARCGRID, and compared with the other vegetation maps in IMAGINE (version 8.2, ERDAS, Inc., Atlanta, GA 30329) using the MATRIX and SUMMARY procedures (ERDAS 1995).

Post-Logging Vegetation (1952)

Estimation of vegetation community distributions prior to sill construction and the extensive wildfires of 1954-1955 was made from SCS 1:24,000 black and white aerial photograph stereo pairs taken during March 1952. Most of the swamp was included in the flight lines of this photograph set. The area north of UTM-Y= 3425000 was not recorded during March 1952; this region was included in flight lines flown

Table 4-2. Vegetation class descriptions and merges created for comparing maps of Okefenokee Swamp vegetation distributions during 1990, 1977, 1952, and before logging occurred (1850-1890).

Vegetation Class and Map	Class Description	Class Groupings for Combined Map 1[a]	Class Groupings for Combined Map 2[b]
1990 Vegetation Map			
Bare Ground-Urban	Bare ground, urban development	Bare Ground-Urban	Bare Ground-Urban
Agriculture-Lawn	Planted fields, road right-of-ways	Bare Ground-Urban	Bare Ground-Urban
Mixed Wet Pine	Slash or pond pine overstory; blackgum, bay, cypress subdominant; shrubs	Wetland Forest	Wetland Forest
Loblolly Bay	Loblolly bay; scattered pine, cypress, blackgum; shrubs	Wetland Forest	Wetland Forest
Ogeechee-Cypress	Ogeechee lime and cypress	Wetland Forest	Wetland Forest
Gum-Maple-Bays	Blackgum dominant; bays, maple, shrubs subdominant	Wetland Forest	Wetland Forest
Pine-Cypress-Hardwoods	Mainly island edge pine-cypress-blackgum-bay mix	Wetland Forest	Wetland Forest
Gum-Bay-Cypress-Shrub	Blackgum dominant with bay, cypress, shrubs subdominant	Gum-Bay-Cypress-Shrub	Wetland Forest

Table 4-2--continued.

Vegetation Class and Map	Class Description	Class Groupings for Combined Map 1[a]	Class Groupings for Combined Map 2[b]
Cypress-Gum-Shrub	Mature cypress; blackgum and shrub understory	Cypress-Gum-Shrub	Wetland Forest
Open Water	Open water	Open Water	Open Water
Sedges-Ferns-Water Lilies	Herbaceous prairie	Prairie	Prairie
Aquatic Grasses	Deep aquatic prairie	Prairie	Prairie
Water Lily	Water lily, Spatterdock	Prairie	Prairie
Shrub	Shrub mixture, mainly titi, fetterbush, and hurrahbush	Shrub	Shrub
Briar-Shrub	Shrub mixture with greenbriar covering most of shrubs	Shrub	Shrub
Mixed Upland-Wetland Shrub	Shrubs of wetland-upland interface	Shrub	Shrub
Bay-Shrub	Loblolly bay with shrub understory	Bay-Shrub	Shrub
Upland Pine	Slash or longleaf pine with palmetto-gallberry shrubs	Upland Pine	Upland Pine
Clearcut-Sparse Pine	Clearcut with/without recent planting	Upland Pine	Upland Pine

Table 4-2--continued.

Vegetation Class and Map	**Class Description**	**Class Groupings for Combined Map 1[a]**	**Class Groupings for Combined Map 2[b]**
Dense Pine	Dense slash or longleaf pine with little shrub understory visible from above	Upland Pine	Upland Pine
Sparse Pine	Scattered slash or longleaf pine in dense upland shrubs	Upland Pine	Upland Pine
1977 Vegetation Map			
Upland Pine	Slash pine, palmetto, gallberry	Upland Pine	Upland Pine
Needle-leaved evergreen	Slash pine with wetland shrub understory	Wetland Forest	Wetland Forest
Mixed Pine	Pine, cypress, blackgum, bay mixture	Wetland Forest	Wetland Forest
Scrub Pine	Pine mixed with young trees	Wetland Forest	Wetland Forest
Bay	Uniform bays with scattered holly and shrubs	Wetland Forest	Wetland Forest
Bay-Cypress	Bays with scattered cypress	Wetland Forest	Wetland Forest
Mixed Cypress	Cypress with bays, blackgum, pine, shrubs	Wetland Forest	Wetland Forest

Table 4-2--continued.

Vegetation Class and Map	Class Description	Class Groupings for Combined Map 1[a]	Class Groupings for Combined Map 2[b]
Scrub	Cypress and blackgum young trees	Wetland Forest	Wetland Forest
Cypress	Cypress with shrub understory	Wetland Forest	Wetland Forest
Blackgum	Blackgum with shrub understory, scattered red maple	Wetland Forest	Wetland Forest
Shrub	Wetland shrubs	Shrub	Shrub
Scrub/Shrub	Young trees mixed with wetland shrubs	Shrub	Shrub
Shrub-Pine	Wetland shrubs with scattered pines	Shrub	Shrub
Shrub-Prairie	Shrub and prairie mixture	Shrub	Shrub
Shrub-Bay	Wetland shrubs with scattered bays	Shrub-Bay	Shrub
Shrub-Cypress	Wetland shrubs with scattered cypress	Shrub-Cypress	Shrub
Cypress-Shrub-Prairie	Cypress with scattered shrubs and prairie patches	Cypress-Shrub-Prairie	Shrub

Table 4-2--continued.

Vegetation Class and Map	Class Description	Class Groupings for Combined Map 1[a]	Class Groupings for Combined Map 2[b]
Scrub-Prairie	Young cypress and blackgum interspersed with prairie patches	Scrub-Prairie	Wetland Forest
Herbaceous Prairie	Shallow prairie with sedges, ferns, broomsedge, and water lily	Prairie	Prairie
Aquatic Prairie	Deepwater prairie with water lilies, spatterdock, bladderwort	Prairie	Prairie
Open Water	Open water lakes and ponds	Open Water	Open Water
1952 Vegetation Map			
Upland Pine	Slash or longleaf pine with palmetto or gallberry understory	Upland Pine	Upland Pine
Wetland Forest	Cypress, blackgum, bay, maple with shrub understory in places	Wetland Forest	Wetland Forest
Shrub	Wetland shrub	Shrub	Shrub
Prairie	Herbaceous or aquatic prairie	Prairie	Prairie

Table 4-2--continued.

Vegetation Class and Map	Class Description	Class Groupings for Combined Map 1[a]	Class Groupings for Combined Map 2[b]
Bare Ground-Urban	Bare ground or urban development	Bare Ground-Urban	Bare Ground-Urban
Open Water	Open water	Open Water	Open Water
Pre-logging Vegetation Map			
Gum-Maple-Bays	Blackgum dominant; bays, maple, shrubs subdominant	Wetland Forest	Wetland Forest
Gum-Bay-Cypress-Shrub	Blackgum dominant with bay, cypress, shrubs subdominant	Gum-Bay-Cypress-Shrub	Wetland Forest
Cypress-Gum-Shrub	Mature cypress; blackgum and shrub understory	Cypress-Gum-Shrub	Wetland Forest
Wetland Pine	Slash or pond pine overstory; blackgum, bay, cypress subdominant; shrubs	Wetland Forest	Wetland Forest
Ogeechee-Cypress	Ogeechee lime and cypress	Wetland Forest	Wetland Forest
Bays	Loblolly, red, or sweet bay; scattered pine, cypress, blackgum; shrubs	Wetland Forest	Wetland Forest

Table 4-2--continued.

Vegetation Class and Map	Class Description	Class Groupings for Combined Map 1[a]	Class Groupings for Combined Map 2[b]
Cypress-Shrub	Cypress with wetland shrub understory	Wetland Forest	Wetland Forest
Bay-Shrub	Loblolly bay with shrub understory	Bay-Shrub	Wetland Forest
Oak-Hickory	Live oak and hickory mixture	Wetland Forest	Wetland Forest
Briar-Shrub	*Smilax spp.* covering wetland shrubs	Shrub	Shrub
Aquatic Prairie	Aquatic or herbaceous prairie	Prairie	Prairie
Upland Pine	Slash or longleaf pine over gallberry, palmetto	Upland Pine	Upland Pine

[a] Classes were grouped within maps for comparisons of similar classes between maps.
[b] Maps with 6 classes were compared with the 1952 vegetation map.

during March 1962. Interpretation of the vegetation community types and distributions in these photographs was accomplished in 2 steps. The region included in the USGS topographic quadrangles around the sill (Pocket, Billy's Island, Craven's Hammock, Spooner) was included in the first set. The photographs included in each quad area were mosaicked and temporarily fixed to a mounting board. A georeferenced, mylar template was created for each quadrangle. The template for each quadrangle included any streams, rivers, and ditches recorded from the edited USGS 1994, 1:100,000 hydrologic feature DLG's, tramline features from the composite tramline coverage, refuge property and wilderness area boundaries digitized from refuge notations on USGS 1:24,000 1994 topographic maps, locations of benchmarks installed for the GPS topographic survey (Chapter 2), and reference tic marks for matching the mylars among quad areas. Mylars were placed over the mosaicked photographs, matching hydrologic features and tramline and refuge boundary evidence where detectable on the photographs. A minimum mapping unit (MMU) of 5.76 ha (1 cm = 240 m x 240 m) was used to delineate areas of vegetation and land features into 6 categories: upland forest, wetland forest, shrub, prairie, open water, bare ground-urban. Boundaries of the vegetation communities were traced from the photographs onto the mylar. Photographs were repositioned as necessary to adjust for edge distortion. Areas smaller than the MMU were not delineated; the predominate vegetation type in the MMU was chosen to represent the location's vegetation type. Mylars were edge-matched and vegetation community boundaries transferred to the adjacent mylar where they were continuous between quad areas. After vegetation boundaries for the quad were traced, each polygon was given a polygon

number and vegetation label identified from the photo stereo pairs. Each mylar map of vegetation polygons was digitized into ARCINFO coverages using the tic marks for geographic reference. Digitized polygons were proofed for discontinuous arcs and missing or multiple labels.

Comparison of the digitized mylars and the 1990 satellite image classification (see below) indicated that some distortion was present on several of the mylar polygon maps, most likely originating on the aerial photographs. This distortion needed correction so that comparisons made among maps would more likely indicate true vegetation changes, rather than changes due to these distortions. Locations were selected from the 1952 and 1990 coverages where similar features were discernable but location differed, indicating that change had not occurred along the vegetation polygon edge but the edge location was distorted, as well as where locations were not distorted. Select, undistorted points assured that fit remained where it already occurred. Multiple points were selected until the calculated transformation order indicated the a root mean square error term of < 100 m. The transformation was then applied to the 1952 coverage and the resultant transformed image was visually compared to the 1990 map to determine if the transformed image was a suitable match, or if additional points were necessary for calculating another transformation to achieve a better match.

The second set of photo interpretation areas was randomly selected to represent regions of the swamp more distant from the sill. Poor photo quality prevented photo interpretation of the entire remainder of the swamp area; therefore, a subset area was randomly selected to represent pre-sill vegetation community distributions in regions

more distant from the sill. The entire swamp coverage was gridded into 5.76 ha cells and numbered with a unique X and Y combination. A random numbers table was used to select 2-digit numbers representing the X and Y values of the cells; the quad map within which the cell occurred became an area selected for photo interpretation. Cells were reselected until 4 separate quad areas were chosen (Double Lakes, Chesser Prairie, Strange Island, Waycross SE). Blackjack Island quadrangle area was originally selected and interpreted, but was later discarded due to extreme photo distortion, as was the lower 1/8 of Chesser Prairie quadrangle. Photo interpretation, edge matching, and digitizing procedures followed those previously discussed. Transformations necessary to correct photo distortions in conversion to the arc coverages were calculated as indicated above.

The final quad areas were joined into one coverage using the transformation matrix developed during edge matching, and gridded to 10 m x 10 m cells in ARCGRID. The "focal majority function" was used in ARCGRID to re-sample the grid to 240 m and 320 m cells, to produce maps of the original interpretation resolution (240 m) and for comparison with the 1977 vegetation map (320 m) (see below). These coverages were used in change assessments discussed below. All comparisons were made with maps of each resolution and class combination to detect artifacts of scaling and vegetation species groupings into classes. The area interpreted from the 1952 photos covered 58% of the total refuge area (Figure 4-5).

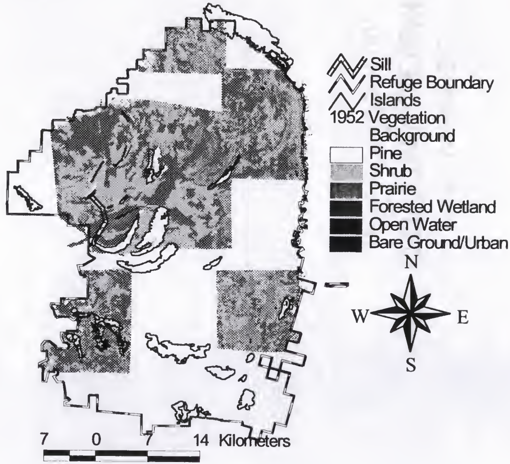


Figure 4-5. Photo interpretation results of Okefenokee National Wildlife Refuge vegetation during 1952.

17 Years With-Sill and 22 Years Post-Fire Vegetation (1977)

A map created by McCaffrey and Hamilton (1982) represents Okefenokee Swamp vegetation 17 years after the Suwannee River Sill was constructed and 22 years after the 1954-1955 wildfires. This map was created by mosaicking 1:30,000 color-infrared aerial photographs recorded during November 1977, and interpreting the vegetation communities with 10 ha MMUs (Hamilton 1982). Vegetation classes used in this interpretation and the re-groupings used for comparisons with the pre-logging, 1952, and 1990 vegetation maps in the current study are listed in Table 4-2. This map included all of the area within the refuge boundary.

The paper map provided by McCaffrey and Hamilton (1982) was converted to digital form (1 pixel=7.15 m) on a flatbed scanner. Extraneous detail was removed and polygon labels representing vegetation types added using ARCEDIT. Transformation of the scanned map was necessary to correct distortion probably originating in the unrectified aerial photos used to make the original map, and to reference it to a coordinate system (NAD27 UTM zone 17) common with the other vegetation maps used in this study. Points along polygon edges were matched to common features discernable in the 10 m resolution merged panchromatic and multispectral 1990 SPOT satellite image (see below); the common feature edges were interpreted to be unchanged during the interval. Adjustments were made throughout the scanned 1977 coverage to match the map polygons to correct locations on the registered image, and areas already in

agreement were not modified. The final transformed map was gridded to 320 m cells in ARCGRID for comparison with the other vegetation maps (Figure 4-6).

30 Years With-Sill and 35 Years Post-Fire (1990)

Swamp vegetation community types and distributions 30 years after sill construction and 35 years after the 1954-1955 wildfires were represented by the vegetation map created from the merged panchromatic and multispectral 1990 SPOT satellite imagery discussed in chapter 2 (Figure 4-7). The 10 m resolution vegetation map was re-sampled using focal majority to 240 m and 320 m grid cells in ARCGRID for comparison with the pre-logging, 1952, and 1977 vegetation maps, and vegetation classes were re-grouped as indicated in Table 4-2.

Wildfire Burn Area Maps

Areas of the swamp burned by wildfires during 1855-1993 were digitized to provide fire polygons to compare with vegetation, logging, and hydrologic feature maps. Estimates of areas burned by wildfires during 1855-1937 were summarized from Trowell (1987); area burned during 1938-1993 was summarized from refuge records. Procedures and data used to develop these maps are discussed in Chapter 5. These fire polygon maps were combined into fire sets (Table 4-3) for comparison with vegetation changes occurring during various intervals, by intersecting fire polygons and dissolving the common borders in ARCEDIT. Overlapping polygons and common borders were dissolved to create maps representing total burn coverage during each interval. These maps were used to determine vegetation occurring prior to fires that subsequently

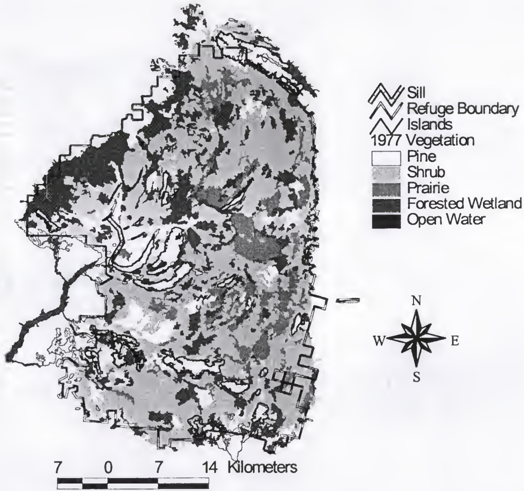


Figure 4-6. Scanned, transformed version of map created by McCaffrey and Hamilton (1980) of Okefenokee Swamp vegetation during 1977.

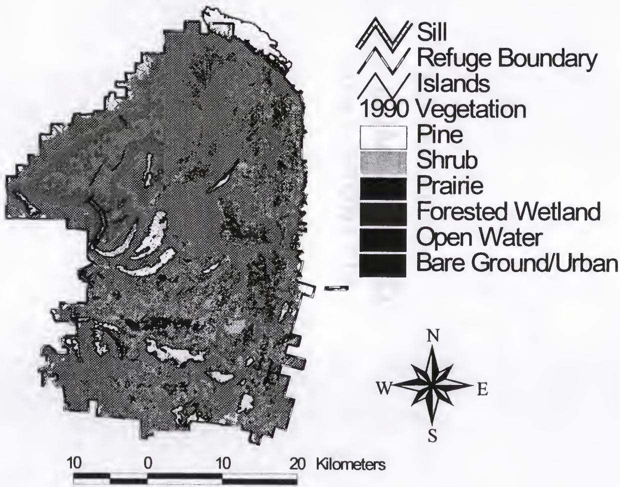


Figure 4-7. Vegetation distributions delineated in a classification of 1990 SPOT satellite imagery.

Table 4-3. Date groupings for wildfire map sets and for vegetation distribution comparisons.

Fire Set	Interval of Years	Data Sources for Wildfire Coverage	Purpose of Selected Time Interval
A	1855-February 1952	digitized polygons (1855-1951), point locations with radius buffers[a] (1939-1951)	includes wildfires occurring from pre-logging to pre-1952 aerial photography
B	March 1952-October 1977	digitized polygons (1952-1968), point locations with radius buffers (1952-1977)	includes wildfires occurring after the 1952 and before the 1977 photography
C	November 1988-11 May 1990	digitized polygons (1978-1989), point locations with radius buffers (1978-1989)	includes wildfires occurring after the 1977 photography and before the 1990 imagery
D	March 1952-December 1955	digitized polygons (1952-1955), point locations with radius buffers (1952-1955)	includes wildfires occurring after the 1952 photography until the end of the extensive 1955 fires
E	November 1977-December 1980	digitized polygons (1978-1979), point locations with radius buffers (1978-1980)	includes wildfires occurring soon after the 1977 photography
F	12-May 1990-1993	digitized polygons (1990-1993), point locations with radius buffers (1990-1993)	includes wildfires occurring soon after the 1990 imagery

[a] "Radius buffers" refers to an estimated burn area. Fires that had size estimates and location in the refuge records, but no location map were plotted as a point. A surrounding circle estimating the fire area was also plotted to roughly approximate the burned area. These areas are referred to as a "radius buffer" around the approximate location of the fire origin.

burned, vegetation regrowth following fires, areas and frequency of reburning, vegetation changes occurring with and without fire, and coincidence of logging and wildfires. Comparisons are detailed in Chapter 5.

Map Comparisons

All comparisons among maps were conducted in IMAGINE using the *matrix* procedure for creating new maps of changed, burned, or logged and burned areas, or the *report summary* procedure for generating reports for each comparison. A common vegetation classification for all maps was used for these comparisons (Table 4-2).

Results

Overall Changes in Vegetation Distributions and Composition

Throughout the nearly 150 years examined in this study there were natural and man-made, direct and indirect, and short-term and continuous disturbances in the swamp environment, processes, and vegetation distributions. Although only a short period of time (1850-1993) was chosen for observation, evidence of many disturbances is present, suggesting the severity of the disturbances and the variance of the system's resilience to different disturbance types.

During the pre-logging surveys of 1850-1890, swamp explorers saw an ecosystem similar in many ways to that existing today. The predominant community types in the swamp during the 40 years prior to intensive logging (1850-1890) were cypress-gum-

shrub (34.8%), *Smilax* spp.-shrub (26.1%, including aquatic and herbaceous prairies), and gum-bay-cypress-shrub (15.3%) (Table 4-4). In 1990 these vegetation types also covered over half of the swamp (24.9% cypress-gum-shrub, 17.9% *Smilax* spp.-shrub including shrub and prairie types, and 13.0% gum-bay-cypress-shrub), with a greater amount of bay communities (12.1% loblolly bay, 18.8% bay-shrub) occurring in 1990 than before logging (1.1%) (Table 4-5). Total forested area was nearly equal during the period of pre-logging surveys (1855-1890) and 1990 (67.4% and 62.8%, respectively), suggesting that by 1990 there may have been recovery of the pre-logging total landscape structure, although not necessarily by the same species or in the same locations (see below). During the intervening period the swamp landscape was more heavily covered by shrubs. In the 58% of the refuge area examined on 1952 aerial photographs, shrub (39.7%) and wet forest (39.5%) areas were nearly equal in total coverage, with prairie (13.0%) and upland pine (7.4%) comprising the remainder (Table 4-6). By 1977, 48.7% of the area in wet forest in 1952 had changed to shrub, probably a result of the 1954-1955 fires (see below), with total wet forest coverage of 28.2% and shrub coverage of 54.5% (Table 4-7). Shrub and wet forest types were varied in composition in 1977, with no forest type > 11.0%, and shrub types <15.0% overall cover. By 1990, wet forest (57.4%) and shrub (28.9%) coverage was nearly equal to pre-logging proportions (63.0% wet forest, 32.6% shrub). Wet forest composition was predominantly cypress-gum-shrub (24.9%), gum-bay-cypress-shrub (13.0%), and loblolly bay (12.1%) in 1990; shrub areas were dominated by bay-shrub (18.8%) and a shrub mixture (7.0%). Upland pine

Table 4-4. Okefenokee Swamp vegetation composition estimated from pre-logging surveys conducted during 1850-1890.

Vegetation[a] Class on Original Map	Area (ha)	% of Total Area	Vegetation Class on Grouped Map	Area (ha)	% of Total Area
Gum-Maple-Bays	826	0.5	Wetland Forest	99628	63.0
Gum-Bay-Cypress-Shrubs	24200	15.3	Upland Pine	6971	4.4
Cypress-Gum-Shrubs	55032	34.8	Shrubs	51515	32.6
Wetland Pine	15601	9.9	Prairie	141	0.1
Oak-Hickory	2021	1.3	Bare Ground-Urban	n/a[b]	n/a
Ogeechee-Cypress	139	0.1	Open Water	n/a	n/a
Bays	1766	1.1			
Cypress-Shrubs	0	0			
Bay-Shrubs	43	0.03			
Pine-Palmetto	6971	4.4			
Smilax-Shrubs	51515	26.0			
Carex-Nymphaea	141	0.1			
Cypress Classes	55171	34.9			
Gum-Bay Classes	26835	17.0			

Vegetation[a] Class on Original Map	Area (ha)	% of Total Area	Vegetation Class on Grouped Map	Area (ha)	% of Total Area
Bay with Shrubs	1809	1.1			
Shrub-Prairie	51656	32.6			

[a] Vegetation classes are listed individually and as grouped for the 6-class map.
[b] Bare Ground-Urban and Open Water classes were not represented in the pre-logging survey notes and if they existed at the time, are assumed to be included in the remaining 4 classes.

Table 4-5. Okefenokee Swamp vegetation composition estimated from an 11 May 1990 SPOT satellite image.

Vegetation Map and Classes	Area (ha)	% of Total Area
21-Class Vegetation Map		
Mixed Wetland Pine	4422	2.8
Loblolly Bay	19357	12.1
Ogeechee-Cypress	66	0.04
Gum-Maple-Bays	4254	2.6
Pine-Cypress-Hardwoods	3167	2.0
Gum-Bay-Cypress-Shrubs	20949	13.0
Cypress-Gum-Shrubs	40023	24.9
Upland Pine	172	0.1
Clearcut-Sparse Pine	18	0.01
Dense Pine	5207	3.2
Sparse Pine	3380	2.1
Shrubs	11295	7.0
Briar-Shrubs	4500	2.8
Mixed Upland-Wetland Shrubs	536	0.3
Bay-Shrubs	30250	18.8
Sedges-Ferns-Water Lilies	10962	6.8
Aquatic Grasses	105	0.1
Water Lilies	1500	0.9
Bare Ground-Urban	307	0.2
Agriculture-Lawn	7	0.004
Open Water	78	0.1

Vegetation Map and Classes	Area (ha)	% of Total Area
Cypress Classes	40089	25.0
Gum-Bay Classes	74810	46.6
Bay with Shrubs	49607	30.9
Shrub-Prairie	28362	17.7
9-Class Vegetation Map		
Wetland Forest	30308	19.5
Gum-Bay-Cypress-Shrubs	20872	13.0
Cypress-Gum-Shrubs	39978	24.9
Upland Pine	8670	5.4
Shrubs	16056	10.1
Bay-Shrubs	30184	18.8
Prairie	977	7.8
Bare Ground-Urban	321	0.2
Open Water	80	0.1
6-Class Vegetation Map		
Wetland Forest	92159	57.4
Upland Pine	8670	5.4
Shrubs	46400	28.9
Prairie	12523	7.8
Bare Ground-Urban	321	0.2
Open Water	80	0.1

Table 4-6. Okefenokee Swamp vegetation composition estimated from 1952 black and white aerial photography.

Vegetation Class	Area (ha)[a]	% of Total Area (240 m MMU)[b]	% of Total Area (320m MMU)
Wetland Forest	36941	39.5	40.9
Upland Pine	6889	7.4	4.8
Shrubs	37124	39.7	41.2
Prairie	12138	13.0	12.9
Bare Ground-Urban	311	0.3	0.2
Open Water	117	0.001	0.06

[a] Approximately 58% of the refuge is included in the interpreted area.
[b] Photographs were interpreted with a minimum mapping unit (MMU) of 240 m. The interpreted map was re-sampled to 320 m cells to compare with the 1977 vegetation map. The proportions resulting from this re-sampling are listed in the last column.

Table 4-7. Estimated Okefenokee Swamp vegetation composition compiled from 1977 color-infrared photography interpreted by McCaffery and Hamilton (1982) with a minimum mapping unit of 320 m.

Vegetation Map and Classes	Area (ha)	% of Total Area
Needle-leaved Evergreen (Wetland Pine)	446	0.3
Mixed Wetland Pine	2304	1.5
Scrub Pine	1829	1.2
Bay	2027	1.3
Bay-Cypress	1525	1.0
Mixed-Cypress	5567	3.5
Scrub	16700	10.6
Cypress	3196	2.0
Blackgum	7821	5.0
Scrub-Prairie	2790	1.8
Upland Pine	9741	6.2
Shrub	21124	13.4
Scrub/Shrub	14988	9.5
Shrub-Pine	2041	1.3
Shrub-Prairie	20737	13.2
Shrub-Bay	11952	7.6
Shrub-Cypress	6469	4.1
Cypress-Shrub-Prairie	8489	5.4
Herbaceous Prairie	4171	2.6
Aquatic Prairie	13540	8.6
Bare Ground-Urban	n/a[a]	n/a
Open Water	4	0.003
Cypress Classes	24167	15.3

Table 4-7--continued

Vegetation Map and Classes	Area (ha)	% of Total Area
Gum-Bay Classes	24521	15.6
Bay with Shrubs	15504	9.8
Shrub-Prairie	61613	39.1
10-Class Vegetation Map		
Wetland Forest	41570	26.4
Upland Pine	9763	6.2
Shrubs	58890	37.4
Shrub-Bay	11967	7.6
Shrub-Cypress	645	4.1
Cypress-Shrub-Prairie	8503	5.4
Scrub-Prairie	2834	1.8
Prairie	17636	11.2
Bare Ground-Urban	n/a	n/a
Open Water	4	0.003
6-Class Vegetation Map		
Wetland Forest	44404	28.2
Upland Pine	9763	6.2
Shrubs	85816	54.5
Prairie	17636	11.2
Bare Ground-Urban	n/a	n/a
Open Water	4	0.003

[a] Bare Ground-Urban class was not represented in the 1977 vegetation map; this class is assumed to be included in the remaining classes.

coverage remained fairly constant since the initial surveys (1850-1890: 4.4%; 1952: 4.8-7.4%; 1977: 6.2%; 1990: 5.4%), while prairie coverage gradually declined (1952: 13.0%; 1977: 11.2%; 1990: 7.8%), and shifted from aquatic to herbaceous prairie type during 1977 to 1990.

Vegetation composition has not changed uniformly across the landscape over time. Some areas and vegetation types have been more constant in composition than others. Distribution of upland pine communities has remained fairly constant since the pre-logging period, despite the effects of fire and logging (see below). Areas in persistent upland pine (i.e., were occupied by upland pine at the start and end of the interval) during 1890-1952 (63.8%), 1952-1977 (71.6%), and 1977-1990 (62.2%) have been intermittently replaced by wet forest communities (1850-1952: 18.5%; 1952-1977: 21.6%; 1977-1990: 26.7%) (Tables 4-8, 4-9, 4-10). Prairie, shrub, and wet forest community distributions have shown less constancy. Areas remaining in prairie vegetation have declined from 78.1% during 1850-1952, to 57.9% during 1952-1977, and to 28.7% during 1977-1990. Replacement has primarily been with shrubs (1952-1977: 35.8%; 1977-1990: 40.1%), although some change to wet forest has also occurred (1850-1952:16.9%; 1952-1977: 5.7%; 1977-1990: 30.9%). Area of persistent wet forest distribution has increased since the pre-logging period (1850-1952: 43.5%; 1952-1977: 45.4%; 1977-1990: 80.0%), while persistent shrub coverage has fluctuated (1850-1952: 38.7%; 1952-1977: 64.5%; 1977-1990: 34.3%). The increase in wet forest coverage during 1977-1990 was due to areas in shrubs during 1952-1977 changing to wet forest during 1977-1990. Most of this change from shrub coverage was to cypress-gum-shrub

Table 4-8. Landscape level vegetation changes occurring in Okefenokee Swamp during 1850-1951. Minimum mapping unit for the comparison is 240 m. Reported values are % of the vegetation class in 1850 occurring in the specified class in 1952.

Vegetation Class in 1850-1890	**Wetland Forest in 1952**	**Upland Pine in 1952**	**Shrub in 1952**	**Prairie in 1952**	**Bare Ground-Urban in 1952**	**Open Water in 1952**
Gum-Maple Bays	5.6	3.5	90.9	0	0	0
Gum-Bay-Cypress-Shrub	49.7	2.6	42.9	4.9	0.02	0
Cypress-Gum	42.1	3.3	43.2	10.7	0.6	0.2
Carex-Nymphaea	16.9	0	5.0	78.1	0	0
Wetland Pine	46.4	16.5	30.3	6.8	0.01	0
Pine Palmetto	18.5	63.8	15.1	2.0	0.6	0
Oak-Hickory	42.7	24.4	27.0	4.9	1.0	0
Ogeechee-Cypress	0	0	0	0	0	0
Smilax-Shrub	31.5	0.2	38.7	29.6	0	0.1
Bays	42.4	0	49.2	8.5	0	0
Cypress-Shrubs	0	0	0	0	0	0
Bay-Shrub	4.2	95.7	1.2	0	0	0

Table 4-9. Landscape-level vegetation changes occurring in Okefenokee Swamp during 1952-1977. Minimum mapping unit for the comparison is 320 m. Reported values are % of the vegetation class in 1952 occurring in the specified class in 1977.

Class in 1952	Upland Forest in 1977	Wetland Forest in 1977	Shrub in 1977	Shrub-Bay in 1977	Shrub-Cypress in 1977	Cypress-Shrub-Prairie in 1977	Scrub-Prairie in 1977	Prairie in 1977	Open Water in 1977	Bare Ground-Urban in 1977
Wetland Forest	2.6	43.4	24.6	6.9	7.6	9.6	2.0	3.4	0	0
Upland Pine	71.6	21.4	3.5	2.3	0.1	0	0.2	0.9	0	0
Shrub	2.3	25.7	39.1	16.1	4.0	5.3	1.3	6.3	0	0
Prairie	0.6	5.0	26.2	1.7	1.8	6.1	0.7	57.9	0.02	0
Bare Ground-Urban	75.3	5.5	7.5	2.0	0	6.9	2.9	0	0	0
Open Water	0	0	51.3	0	0	0	0	48.6	0.1	0

Table 4-10. Landscape-level vegetation changes occurring in Okefenokee Swamp during 1977-1990. Minimum mapping unit for the comparison is 320 m. Reported values are % of the vegetation class in 1977 occurring in the specified class in 1990.

Class in 1977	Upland Pine in 1990	Wetland Forest in 1990	Shrub in 1990	Gum-Bay-Cypress-Shrubs in 1990	Cypress-Gum-Shrubs in 1990	Bay-Shrubs in 1990	Prairie in 1990	Open Water in 1990	Bare Ground-Urban in 1990[a]
Upland Pine	62.2	15.9	5.1	3.7	7.1	4.9	0.4	0	0.8
Wetland Forest	2.5	38.8	1.5	17.9	23.3	13.1	2.9	0	0.1
Shrubs	1.0	7.3	9.6	9.8	35.6	28.0	8.7	0.1	0.0002
Shrub-Bay	0.8	42.3	0.6	27.3	20.9	7.5	0.5	0	0.003
Shrub-Cypress	0.3	9.5	3.5	19.8	35.2	29.4	2.4	0	0
Cypress-Shrub-Prairie	0.2	3.1	6.7	6.8	30.8	43.4	9.1	0	0
Scrub-Prairie	4.4	8.6	6.7	11.7	40.8	22.9	5.0	0	0
Prairie	0.04	3.4	16.4	4.7	22.8	23.7	28.7	0.3	0.001
Open Water	0	0	0	0	77.6	0	22.4	0	0

[a] Bare Ground-Urban class was not represented in the 1977 vegetation map; this class is assumed to be included in the remaining classes.

(23.3%) and gum-bay-cypress-shrub (17.9%) wet forest types in areas of shrub, shrub-bay, shrub-cypress, and cypress-shrub-prairie vegetation types in 1977 (Table 4-9).

Logging Impacts

Areas logged during 1890-1942 contained wet forest (88.2%), shrubland (4.3%), upland pine (7.5%), and prairie (0.1%) before logging occurred (Table 4-11). By 1952 the proportions of wet forest (41.6%), shrub (45.7%), and prairie (4.8%) communities had changed in the logged areas from pre-logging amounts, while upland pine remained fairly constant (7.3%) (Table 4-12). These coverages remained almost unchanged in 1977 (Table 4-13). By 1990 wet forest coverage in logging tramlines had increased to 69.5%, and shrub coverage had decreased to 18.6%; prairie (3.8%) and upland pine (7.9%) remained nearly constant (Table 4-14). Although the total coverage of wet forest in the logged areas had increased by 1990 to levels similar to pre-logging (1850-1890), the proportions of forest types differed. A mixture of cypress-gum-shrub (21.4%), loblolly bay (20.6%), and gum-bay-cypress-shrub (15.6%) replaced the areas dominated before logging by cypress-gum-shrub (56.1%), gum-bay-cypress-shrub (18.4%), and wet pine (7.9%).

Vegetation changes occurring during 1952-1990 in the logged areas were similar to those occurring in the swamp overall (Table 4-15). During 1952-1977 in previously logged areas, persistent upland pine (85.7%) and persistent wet forest (58.0%) were in slightly higher proportions than in the swamp as a whole, whereas persistent shrubland (48.7%) and persistent prairie (41.8%) were lower (Table 4-16). This trend continued

Table 4-11. Estimated composition of logging tramline areas before logging occurred, recorded in surveys conducted during 1850-1890.

Vegetation Class	**Area (ha)**	**% of Total Area**
Gum-Maple-Bays	150	0.5
Gum-Bay-Cypress-Shrubs	6013	18.4
Cypress-Gum-Shrubs	18335	56.1
Carex-Nymphaea	43	0.1
Wetland Pine	2582	7.9
Pine-Palmetto	2451	7.5
Oak-Hickory-*Magnolia*	654	2.0
Ogeechee-Cypress	72	0.2
Smilax-Shrubs	1405	4.3
Bays	1013	3.1
Cypress-Shrub	0	0
Bay-Shrub	0	0
6-Class Map[a]		
Wetland Forest	28826	88.2
Shrubs	1405	4.3
Upland Pine	2451	7.5
Prairie	43	0.1

[a] Bare Ground-Urban and Open Water were not distinguished from the other class types in this map.

Table 4-12. Estimated composition during 1952 of areas previously logged.

Vegetation Class	Area (ha)	% of Total Area
Wetland Forest	9357	41.6
Shrubs	10268	45.7
Prairie	1072	4.8
Upland Pine	1629.6	7.3
Bare Ground-Urban	127.9	0.6
Open Water	14.1	0.1

Table 4-13. Estimated composition during 1977 of areas previously logged.

Vegetation Class	Area (ha)	% of Total Area
Upland Pine	3096	9.7
Needle-Leaved Evergreen (Wetland Pine)	27	0.1
Bay	856	2.7
Cypress	696	2.2
Blackgum	4038	12.6
Bay-Cypress	99	0.3
Mixed Cypress	1440	4.5
Cypress-Shrub-Prairie	894	2.8
Mixed Pine	193	0.6
Herbaceous Prairie	271	0.9
Aquatic Prairie	895	2.8
Shrubs	3012	9.4
Scrub	4080	12.7
Scrub/Shrub	3570	11.1
Shrub-Pine	317	1.0
Shrub-Cypress	1082	3.4
Shrub-Bay	4695	14.7
Shrub-Prairie	2011	6.3
Scrub-Pine	148	0.5
Scrub-Prairie	617.3	1.9
6-Class Map[a]		
Wetland Forest	12194	38.1
Shrubs	15581	48.6
Upland Pine	3096	9.7
Prairie	1166	3.6

[a] Bare Ground-Urban and Open Water classes were not included in the original map.

Table 4-14. Estimated composition during 1990 of areas previously logged.

Vegetation Class	Area (ha)	% of Total Area
Upland Pine	40.7	0.1
Dense Pine	1356	4.1
Sparse Pine	1205	3.7
Clearcut-Sparse Pine	5	0.02
Ogeechee-Cypress	7	0.02
Gum-Maple-Bays	1833	5.6
Gum-Bay-Cypress-Shrubs	5095	15.6
Mixed Wet Pine	1217	3.7
Loblolly Bay	6759	20.6
Pine-Cypress-Hardwoods	851	2.6
Cypress-Gum-Shrubs	7003	21.4
Bay-Shrubs	4423	13.5
Briar-Shrubs	331	1.0
Shrubs	1111	3.4
Mixed Upland/Wetland Shrubs	214	0.7
Water Lily	90	0.3
Sedges-Ferns-Water Lilies	1100	3.4
Aquatic Grasses	15	0.1
Open Water	5.7	0.02
Bare Ground-Urban	105	0.32
Agriculture-Lawn	2	0.005
6 Class Map		
Wetland Forest	22765	69.5
Shrubs	6079	18.6

Table 4-14--continued.

Vegetation Class	Area (ha)	% of Total Area
Upland Pine	2606	8.0
Prairie	1205	3.7
Bare Ground-Urban	106	0.3
Open Water	6	0.01

Table 4-15. Proportions of the entire swamp and logged areas that remained in persistent vegetation types between intervals, and the predominant type of replacement where changes occurred during 1952-1977 and 1977-1990.

Vegetation Type	% of Swamp in Type, 1952-1977	% of Logged Area in Type, 1952-1977	% of Swamp in Type, 1977-1990	% of Logged Area in Type, 1977-1990
Persistent Vegetation Type				
Upland Pine	76.6	85.7	62.2	66.6
Wetland Forest	45.4	58.0	80.0	86.0
Shrubs	64.5	48.7	34.3	21.0
Prairie	57.9	41.8	28.7	29.1
Predominant Change Type				
Upland Pine	21.7 (Wetland Forest)	9.2 (Wetland Forest)	26.7 (Wetland Forest)	24.7 (Wetland Forest)
Wetland Forest	48.7 (Shrubs)	37.4 (Shrubs)	15.6 (Shrubs)	10.5 (Shrubs)
Shrubs	27.0 (Wetland Forest)	32.5 (Wetland Forest)	41.2 (Wetland Forest)	71.2 (Wetland Forest)
Prairie	35.8 (Shrubs)	43.0 (Shrubs)	40.1 (Shrubs) 30.9 (Wetland Forest)	36.6 (Wetland Forest) 34.0 (Shrubs)

Table 4-16. Vegetation changes occurring during 1952-1977 in areas logged during 1890-1942. Minimum mapping unit for the comparison is 320 m. Values are % of the vegetation class in 1952 occurring in the specified class in 1977.

Class in 1952	Upland Pine in 1977	Forested Wetland in 1977	Shrubs in 1977	Shrub-Bay in 1977	Shrub-Cypress in 1977	Cypress-Shrub-Prairie in 1977	Scrub-Prairie in 1977	Prairie in 1977	Open Water in 1977
Upland Pine	85.7	9.2	3.4	1.4	0.1	0	0.1	0.2	0
Forested Wetland	3.5	55.3	19.4	9.5	4.8	3.7	2.7	1.1	0
Shrubs	2.5	30.1	32.2	25.5	2.6	2.4	2.4	2.2	0
Prairie	2.5	9.8	32.1	0.6	1.6	8.7	3.0	41.8	0
Bare Ground-Urban[a]	79.9	5.0	8.2	2.4	0	4.4	0	0	0
Open Water	0	0	100	0	0	0	0	0	0

[a] Bare Ground-Urban class was not represented in the 1977 vegetation map; this class is assumed to be included in the remaining classes.

during 1977-1990; by 1990 persistent prairie, wet forest, and upland pine occurred in proportions similar between logged areas and the swamp overall, while persistent shrubs were less abundant in logged areas (21.0%) (Table 4-17). The types of changes occurring in the logged areas were similar to those occurring throughout the swamp during these intervals. Prairie replacement during 1952-1977 and 1977-1990 was primarily by shrub (1952-1977: logged 43.0%, overall 35.8%; 1977-1990: logged 34.0%, overall 40.1%). Prairie was also replaced with wet forest, although less during 1952-1977 (overall 5.7%, logged 12.8%) than during 1977-1990 (overall 30.9%, logged 36.6%). Upland pine was more frequently replaced by wet forest in the swamp overall (21.7%) than logged (9.2%) areas during 1952-1977, and replaced nearly equally by wet forest during 1977-1990 in the swamp overall (26.7%) and logged (24.7%) areas. Wet forest replacement by shrubs has decreased since 1952. During 1952-1977 wet forest was replaced by shrubs less frequently in logged (37.4%) than the swamp overall (48.7%); and, during 1977-1990 wet forest was replaced in lower proportions by shrubs in logged areas (10.5%) than by shrubs elsewhere (15.6%).

Fire and Vegetation Change

Effects of fire on Okefenokee Swamp vegetation distribution and composition in the landscape are detailed in Chapter 5. A summary of the swamp's response to wildfires is provided here.

Prior to 1952 most wildfires in the swamp occurred in wet forest (61.0%; value represents the area of this vegetation type that burned during the specified interval),

Table 4-17. Vegetation changes occurring during 1977-1990 in areas logged during 1890-1942. Minimum mapping unit for the comparison is 320 m. Values are % of the vegetation class in 1977 occurring in the specified class in 1990.

Class in 1977	Forested Wetland in 1990	Gum-Bay-Cypress-Shrub in 1990	Cypress-Gum-Shrub in 1990	Bay-Shrub in 1900	Shrub in 1990	Upland Pine in 1990	Prairie in 1990	Open Water in 1990	Bare Ground-Urban in 1990[a]
Upland Pine	16.0	4.0	4.7	2.0	6.0	66.6	0.1	0	0.7
Forested Wetland	54.5	17.3	14.5	9.5	1.0	1.3	2.1	0	0.01
Shrub	13.1	11.7	39.0	24.5	3.5	1.8	6.4	0.01	0
Shrub-Bay	46.0	23.5	22.5	7.4	0.4	0.1	0.2	0	0.001
Shrub-Cypress	13.2	18.9	38.7	26.5	1.5	0	1.1	0	0
Cypress-Shrub-Prairie	3.8	3.4	28.6	43.9	10.0	0.8	9.4	0	0
Scrub-Prairie	19.4	30.7	35.6	8.4	1.0	3.1	1.8	0	0
Prairie	6.1	8.1	22.4	19.8	14.2	0.2	29.1	0	0
Open Water	0	0	0	0	0	0	0	0	0

[a] Bare ground-Urban class was not represented in the 1977 vegetation map; this class is assumed to be included in the remaining classes.

shrub (34.6%), and upland pine (4.4%) vegetation, and these fires were primarily in cypress-gum-shrub (38.9%), gum-bay-cypress-shrub (14.5%), and *Smilax* spp.-shrub (34.6%) (Table 4-18). By 1952 these burned areas had been revegetated with greater proportions of shrubs (41.3%) and prairie (14.0%), and less wet forest (39.7%) than before burning. Upland pine coverage remained persistent (4.5%). Prior to logging (1850-1890), 26% of the swamp surface fuel load (excluding peat) was in logging tramlines (Table 4-19); 95.0% of this logging tramline fuel was wet forest, and 89.0% of this was dominated by cypress (Table 4-20). During 1890-1942, 26.0% of the swamp was logged, and 23.0% of the area that burned during 1855-1952 was in logged areas (Table 4-21). Between 1890 and 1952, 64.2% of the logged area burned by wildfires.

During 1952-1976 wildfires occurred in nearly all of the swamp, in vegetation types in proportion nearly equal to the overall swamp vegetation composition; vegetation that burned included wet forest (40.4%), shrub (39.1%), prairie (13.7%), and upland pine (6.3%) (Table 4-22). These vegetation types were replaced by shrubs (59.8%), wet forest (18.0%), prairie (16.3%), and upland pine (6.0%) by 1977. Most of the subsequent fires occurred in upland pine (56.5%), shrub (24.1%), and wet forest (15.2%) communities (Table 4-23). By 1990 these burned areas had revegetated as upland pine (53.9%), wet forest (33.0%), shrub (11.9%), and prairie (1.1%).

Vegetation Changes in the Areas Affected by the Suwannee River Sill

Two areas of the swamp have incurred hydrologic alterations since the sill was constructed. An area of 23,335 ha in the western and central swamp (Figure 3-9) is

Table 4-18. Vegetation types that burned after 1855 and before 1952, and the types of vegetation that occurred in the burned areas in 1952.

Vegetation Type that Burned After 1855 and Before 1952	Proportion[a] of Sampled Area	Vegetation Type Occurring in Burned Areas by 1952	Proportion of Sampled Area
Gum-Maple Bays	0.6	Bare Ground-Urban	0.3
Gum-Bay-Cypress-Shrub	14.5	Wet Forest	39.7
Cypress-Gum-Shrub	38.9	Open Water	0.2
Wetland Pine (Pond and Slash Pines)	4.3	Prairie	14.0
Pine-Palmetto	4.4	Shrub	41.3
Oak-Hickory-Magnolia	1.6	Upland Pine	4.5
Smilax-Shrub	34.6		
Bays	1.1		
Bay-Shrub	0.03		
Ogeechee-Cypress	0		
Cypress-Shrub	0		

[a] Proportions are of the area sampled, not necessarily for the entire swamp. Unburned area = 97287 ha, burned area = 87601 ha.

Table 4-19. Logging tramline fuel load estimates.

Vegetation Type	1855 (kg)	1952 (kg)[a]	1977 (kg)	1990 (kg)
Wet Forest	$1.8x10^8$	$7.9x10^7$	$4.6x10^7$	$1.0x10^8$
Shrub[b]	$3.8x10^6$	$2.8x10^7$	$5.4x10^7$	$1.7x10^7$
Prairie	$9.5x10^4$	$2.4x10^6$	$2.6x10^6$	$2.7x10^6$
Upland Pine	$5.8x10^6$	$3.8x10^6$	$7.3x10^6$	$6.1x10^6$
Total Tramline Fuel[c]	$1.9x10^8$	$1.1x10^8$	$1.1x10^8$	$1.3x10^8$
Total Refuge Area Fuel	$7.5x10^8$	$4.6x10^8$	$6.7x10^8$	$9.5x10^8$

[a] Interpreted area includes 58% of the refuge; fuel volumes have been proportionally adjusted to compare with other sample periods.
[b] Pre-logging shrub area includes some prairie; these types were not readily distinguishable in many of the survey descriptions.
[c] Area logged in tramlines is 26% of total refuge area.

Table 4-20. Fuel load composition for fires occurring during 1855-1951, 1952-1976, and 1977-1990.

Vegetation Type	Fuel Load Before Logging Began (kg/ha)	Fuel Load in 1952 (kg/ha)	Fuel Load in 1977 (kg/ha)	Fuel Load in 1990 (kg/ha)
Prairie	$1.5x10^6$	$1.3x10^8$	$1.9x10^8$	$1.3x10^8$
Shrub	$6.9x10^8$	$5.0x10^8$	$7.9x10^8$	$2.2x10^8$
Wet Forest (models 6 and 4)	$2.9X10^9$	$1.5x10^9$	$1.1x10^9$	$2.7x10^9$
Upland Pine	$8.0x10^7$	$7.9x10^7$	$1.1x10^8$	$1.0x10^8$
Cypress Only (model 4)	$2.3x10^9$	unknown[a]	$2.6x10^8$	$1.6x10^9$
% Wet Forest Area in Cypress	55.4	unknown	9.1	32.7
% Wet Forest Fuel Load in Cypress	79.2	unknown	23.5	59.8

[a] Cypress was not separated from other forested wetland species in the interpretation of the 1952 aerial photos.

Table 4-21. Proportion of wildfires in logged and unlogged tramline areas.

Wildfire Year Period	% of Area Logged and Burned[a]	% of Area Not Logged and Burned	Total Burned Area (ha)	% of Logged Area that Burned	% of Area Unburned and Logged	% of Area Unburned and Not Logged	Total Unburned Area (ha)
1855-1952	23	77	87601	64	12	88	97287
1952-1955	20	80	132803	80	7	93	91142
1952-1977	18	83	91371	74	14	86	38785
1977-1990	17	83	1880	8	11	89	35583
1990-1993	9	91	13697	6	18	82	113664

[a] Total logged tramline area is 32682 ha or 26% of refuge area.

Table 4-22. Vegetation types that burned during 1954-1955, and the types of vegetation that occurred in the burned areas by 1977.

Vegetation Type that Burned during 1954-1955	Proportion[a] of Sampled Area	Vegetation Type Occurring in Burned Areas by 1977	Proportion of Sampled Area
Bare Ground-Urban	0.4	Upland Pine	6.0
Wet Forest	40.4	Needle-Leaved Evergreen	0.3
Open Water	0.1	Bay	1.4
Prairie	13.7	Cypress	2.8
Shrubs	39.1	Blackgum	0.1
Upland Pine	6.3	Bay-Cypress	1.3
		Mixed-Cypress	2.3
		Cypress-Shrub-Prairie	7.1
		Mixed Pine	0.2
		Herbaceous Prairie	3.4
		Aquatic Prairie	12.9
		Shrubs	16.0
		Scrub	7.6
		Scrub-Shrub	9.8
		Shrub-Pine	0.7
		Shrub-Cypress	3.1
		Shrub-Bay	6.1
		Shrub-Prairie	17.0
		Scrub-Pine	0.6
		Scrub-Prairie	1.4

[a] The photo interpreted area included 58% of the refuge.

Table 4-23. Vegetation types that burned after 1955 and before 1990, and the types of vegetation that occurred in the burned areas in 1990.

Vegetation Type that Burned After 1955 and Before 1990	Proportion of Sampled Area	Vegetation Type Occurring in Burned Areas in 1990	Proportion of Sampled Area
Upland Pine	56.5	Upland Pine	0.3
Needle-Leaved Evergreen (wetland)	3.3	Dense Pine	30.2
Cypress	7.4	Sparse Pine	23.4
Cypress-Shrub-Prairie	1.6	Clearcut-Sparse Pine	0.02
Aquatic Prairie	0.3	Pine-Cypress-Hardwoods	16.2
Shrubs	8.8	Mixed Upland-Wetland Shrubs	0.03
Scrub	3.5	Briar-Shrub	0.1
Scrub-Shrub	2.4	Mixed Wet Pine	1.6
Shrub-Prairie	11.3	Bay-Shrub	9.7
Scrub-Pine	1.0	Cypress-Gum-Shrub	11.7
Scrub-Prairie	3.6	Loblolly Bay	0.6
		Shrub	2.1
		Gum-Bay-Cypress-Shrub	2.9
		Sedge-Fern-Water Lily	1.1

affected by impounded water during high water conditions; this area decreases with declining water levels. The Cypress Creek watershed has also had elevated average water levels in 5140 ha since the sill was constructed, but during high water level conditions this area may actually drain more rapidly due to a reversal of the water surface gradient towards the Suwannee River (see Chapter 3). The following discussion addresses vegetation changes occurring in these areas.

During 1952-1990 nearly all of the change that occurred in each vegetation type in the western and central Suwannee River Sill impact area (see chapter 3) was to wet forest (Table 4-24, Figure 4-8). Most of the wet forest in 1990 in this region was composed of gum-bay-cypress-shrub, cypress-gum-shrub, and loblolly bay (Table 4-25), and most of the change occurring during 1952-1990 was to these types from shrub-bay, shrub-prairie, shrub, and scrub, during 1977-1990 (Tables 4-26, 4-27). Conversion to shrub types in this area was primarily to bay-shrub and other shrub-wet forest associations.

Prior to sill construction, vegetation change in the sill-affected area occurred in shrub, wet forest, and prairie vegetation types. Much of this transition can be attributed to succession following logging. In the sill impoundment-affected area during 1977-1990, changes in vegetation compositions were occurring at a much greater rate than those changes occurred during 1952-1977 (Table 3-11). Rates of changes outside of this area were also greater during 1977-1990 than 1952-1977 for wet forest, shrub, and prairie. However, nearly all upland pine change that occurred during 1952-1990 was complete by 1977. In the sill impoundment impact area wet forest area initially

Table 4-24. Vegetation changes occurring during 1952-1990 in the river floodplain area most likely affected by the sill's impoundment and in the Cypress Creek watershed area. Minimum mapping unit for the comparison is 240 m. Values are % of the vegetation class in 1952 occurring in the specified class in 1990.

Area and Class in 1952	Wetland Forest in 1990	Shrubs in 1990	Prairie in 1990	Upland Pine in 1990	Open Water in 1990	Bare Ground-Urban in 1990
Floodplain Area						
Wetland Forest	77.3	20.8	1.2	0.7	0	0
Shrubs	93.4	4.2	1.5	0.7	0	0
Prairie	47.4	33.2	19.2	0.3	0	0
Upland Pine	73.6	9.9	1.0	15.1	0	0.5
Open Water	99.5	0.5	0	0	0	0
Bare Ground-Urban	100.0	0	0	0	0	0
Cypress Creek Area						
Wetland Forest	57.0	42.2	0.1	0.6	0	0
Shrubs	53.1	42.0	0.2	4.7	0	0
Prairie	47.2	52.3	0.5	0	0	0
Upland Pine	12.3	0	0	87.7	0	0
Open Water	0	0	0	0	0	0
Bare Ground-Urban	100.0	0	0	0	0	0

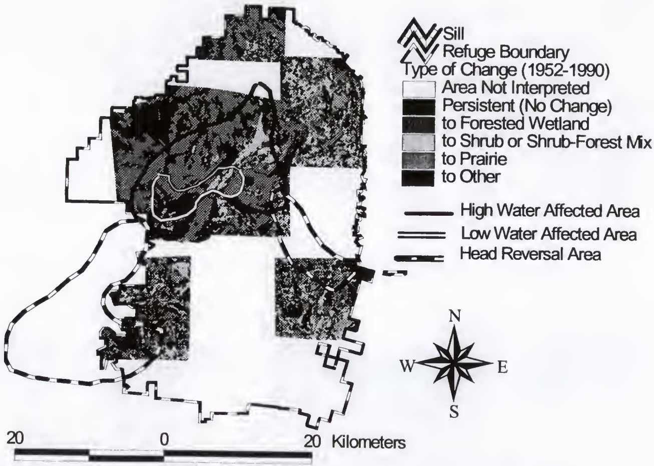


Figure 4-8. Areas of vegetation change occurring during 1952-1990, and regions where the swamp hydrologic environment has been affected by the sill.

Table 4-25. Vegetation changes occurring during 1952-1990 in the floodplain area most likely affected by the sill's impoundment and the Cypress Creek watershed area. Classes from the 1990 map have not been grouped; values are % of the vegetation class in 1952 occurring in the specified class of the ungrouped map in 1990. Minimum mapping unit for the comparison is 240 m.

Vegetation Class and Area in 1952	Upland Pine in 1990	Ogeechee-Cypress in 1990	Gum-Maple-Bays in 1990	Water Lily in 1990	Gum-Bay-Cypress-Shrub in 1990	Mixed Wetland Pine in 1990	Sedges-Ferns-Water Lily in 1990	Briar-Shrubs in 1990	Bare Ground-Urban in 1990	Agriculture-Lawn in 1990	Clearcut-Sparse Pine in 1990
Floodplain Area											
Bare Ground-Urban	0	0	0	0	0	0	0	0	0	0	0
Wetland Forest	0.04	0.1	1.9	0.2	24.7	0.1	1.1	3.3	0	0	0
Open Water	0	0	0	0	9.5	0	0	0.5	0	0	0
Prairie	0.2	0	0.5	10.0	13.2	0.04	9.2	6.4	0	0	0
Shrubs	0.01	0	1.5	0.2	35.9	0.1	1.3	1.0	0	0	0
Upland Pine	0	1.8	2.5	0.7	16.3	1.4	0.3	6.1	0.5	0	0
Total Class Area in 1990 (ha)	10	30	350	339	6157	32	494	639	5	0	0
% of Total Area in Class in 1990	0.04	0.1	1.6	1.5	27.5	0.1	2.2	2.9	0.02	0	0

Table 4-25--continued.

Vegetation Class and Area In 1952	Upland Pine In 1990	Ogeechee-Cypress In 1990	Gum-Maple-Bays In 1990	Water Lily In 1990	Gum-Bay-Cypress-Shrub In 1990	Mixed Wetland Pine In 1990	Sedges-Ferns-Water Lily In 1990	Briar-Shrubs In 1990	Bare Ground-Urban In 1990	Agriculture-Lawn In 1990	Clearcut-Sparse Pine In 1990
Cypress Creek Area											
Bare Ground-Urban	0	0	0	0	0	1.5	0	0	0	0	0
Wetland Forest	0	0	0	0	0.3	27.6	0.1	0	0	0	0
Open Water	0	0	0	0	0	0	0	0	0	0	0
Prairie	0	0	0	0	0	1.2	0.5	0	0	0	0
Shrubs	0	0	0	0	2.7	14.8	0.2	0	0	0	0
Upland Pine	0	0	0	0	0	0	0	0	0	0	0
Total Class Area In 1990 (ha)	0	0	0	0	18	373	3.0	0	0	0	0
% of Total Area In Class In 1990	0	0	0	0	1.0	21.5	0.2	0	0	0	0

Table 4-25--continued.

Vegetation Class and Area in 1952	Aquatic Grasses in 1990	Open Water in 1990	Bay-Shrub in 1990	Cypress-Gum-Shrub in 1990	Loblolly Bay-Shrub in 1990	Shrubs in 1990	Dense Pine in 1990	Sparse Pine in 1990	Mixed Upland-Wetland Shrubs in 1990	Pine-Cypress-Hardwoods in 1990	Total Sill Impoundment Area (ha) in 1952	% of Total Area in Class in 1952
Floodplain Area												
Bare Ground-Urban	0	0	0	0	100.0	0	0	0	0	0	2	<0.00
Wetland Forest	0	0	17.2	24.9	24.3	0.04	0.4	0.3	0.3	1.3	8905	39.8
Open Water	0	0	0	10.5	79.5	0	0	0	0	0	32	<0.00
Prairie	0	0	26.7	26.0	7.3	0.01	0.04	0.1	0	0.4	2964	13.2
Shrubs	0	0	3.0	21.2	34.4	0.1	0.2	0.5	0.03	0.5	9490	42.4
Upland Pine	0	0	1.7	9.7	26.6	0	8.3	6.8	2.2	15.3	980	4.4
Total Class Area in 1990 (ha)	0	0.02	2621	5102	5933	17	140	133	46	325		
% of Total Area in Class in 1990	0	<0.01	11.7	22.8	26.5	0.1	0.6	0.6	0.2	1.5		
Cypress Creek Area												
Bare ground-Urban	0	0	0	98.5	0	0	0	0	0	0	5	0.3

Table 4-25--continued.

Vegetation Class and Area in 1952	Aquatic Grasses in 1990	Open Water in 1990	Bay-Shrub in 1990	Cypress-Gum-Shrub in 1990	Loblolly Bay-Shrub in 1990	Shrubs in 1990	Dense Pine in 1990	Sparse Pine in 1990	Mixed Upland-Wetland Shrubs in 1990	Pine-Cypress-Hardwoods in 1990	Total Sill Impoundment Area (ha) in 1952	% of Total Area in Class in 1952
Wetland Forest	0	0	42.2	26.3	1.8	0	0.3	0.4	0	1.1	1056	60.9
Open Water	0	0	0	0	0	0	0	0	0	0	0	0
Prairie	0	0	50.8	46.0	0	1.5	0	0	0	0	123	7.1
Shrubs	0	0	42.0	28.6	6.3	0	3.7	1.1	0	0.8	537	31.0
Upland Pine	0	0	0	5.6	6.6	0	46.9	40.9	0	0.1	12	0.7
Total Class Area in 1990 (ha)	0	0	733	493	53	2	29	14	0	16	1733	
% of Total Area in Class in 1990	0	0	42.3	28.4	3.1	0.1	1.7	0.8	0	0.9		

Table 4-26. Vegetation changes occurring during 1977-1990 in the floodplain area most likely affected by the sill's impoundment effects and the Cypress Creek watershed area. Neither map consisted of grouped classes; values are % of the vegetation class in the ungrouped 1977 map in the specified class of the ungrouped map in 1990. Minimum mapping unit for the comparison is 240 m.

Vegetation Class in 1977	Upland Pine in 1990	Ogeechee-Cypress in 1990	Gum-Maple-Bays in 1990	Water Lily in 1990	Gum-Bay-Cypress-Shrub in 1990	Mixed Wet Pine in 1990	Sedges-Ferns-Water Lily in 1990	Briar-Shrubs in 1990	Bare Ground-Urban in 1990	Agricultur e-Lawn in 1990	Clearcut-Sparse Pine in 1990
Floodplain Area											
Upland Pine	0.8	0.8	1.9	0.2	11.8	0.4	0.01	4.6	0.4	0	0
Needle-leaved Evergreen	0	0	0	0	0	0	0	0	0	0	0
Bay	0	0	14.4	0	6.8	0	0	0.2	0	0	0
Cypress	0	0	0	0	4.2	0	3.3	11.1	0	0	0
Blackgum	0	0	18.7	0	24.6	0	0	0	0	0	0
Bay-Cypress	0	0	5.6	0	12.8	0	0	0	0	0	0
Mixed Cypress	0	0	0.01	0.01	34.5	0	0.4	0.2	0	0	0
Cypress-Shrub-Prairie	0	0	0	0	7.5	0	2.4	0.04	0	0	0
Mixed Pine	0	0.3	0	0	38.3	0	0	0.8	0	0	0
Herbaceous Prairie	0	0	1.1	0	17.2	0.3	11.1	1.4	0	0	0
Aquatic Prairie	0	1.6	0	19.6	2.3	0.1	19.8	16.5	0	0	0

Table 4-26 continued.

Vegetation Class in 1977	Upland Pine in 1990	Ogeechee-Cypress in 1990	Gum-Maple-Bays in 1990	Water Lily in 1990	Gum-Bay-Cypress-Shrub in 1990	Mixed Wet Pine in 1990	Sedges-Ferns-Water Lily in 1990	Briar-Shrubs in 1990	Bare Ground-Urban in 1990	Agricultur e-Lawn in 1990	Clearcut-Sparse Pine in 1990
Open Water	0	0	0	0	0	0	0	0	0	0	0
Shrubs	0	0	0.02	0.10	30.0	0.7	0.2	1.0	0	0	0
Scrub	0	0.05	0.9	0.1	43.9	0.02	0.4	0.8	0.01	0	0
Scrub-Shrub	0.3	0	0	0	31.8	0.3	0	0.1	0	0	0
Shrub-Pine	0	0	0	0	0.8	0	0	22.9	0	0	0
Shrub-Cypress	0	0	0	0	22.5	0	0.8	0	0	0	0
Shrub-Bay	0	0	0.4	0	39.8	0	0	0	0	0	0
Shrub-Prairie	0	0	0	0	34.6	0.04	3.3	0	0	0	0
Scrub-Pine	0	0	0	0	0	0	0	0	0	0	0
Scrub-Prairie	0	0.6	2.8	0.8	40.8	0	0	5.6	0	0	0
Total Class Area (ha) in 1990	10	24	325	373	6234	22	657	632	4	0	0
% of Total Area in Class in 1990	0.04	0.1	1.4	1.6	26.7	0.1	0.1	2.7	0.02	0	0
Cypress Creek Area											

Table 4-26 continued.

Vegetation Class in 1977	Upland Pine in 1990	Ogeechee-Cypress in 1990	Gum-Maple-Bays in 1990	Water Lily in 1990	Gum-Bay-Cypress-Shrub in 1990	Mixed Wet Pine in 1990	Sedges-Ferns-Water Lily in 1990	Briar-Shrubs in 1990	Bare Ground-Urban in 1990	Agricultur e-Lawn in 1990	Clearcut-Sparse Pine in 1990
Upland Pine	0	0	0	0	1.0	15.0	0	0	0	0	0
Needle-leaved Evergreen	0	0	0	0	0	0	0	0	0	0	0
Bay	0	0	0	0	0.3	60.7	0	0	0	0	0
Cypress	0	0	0	0	0	0	0	0	0	0	0
Blackgum	0	0	0	0	0	0	0	0	0	0	0
Bay-Cypress	0	0	0	0	0	0	0	0	0	0	0
Mixed Cypress	0	0	0	0	24.1	0.8	0	0	0	0	0
Cypress-Shrub-Prairie	0	0	0	0	0	0	0.1	0	0	0	0
Mixed Pine	0	0	0	0	0	10.8	0	0	0	0	0
Herbaceous Prairie	0	0	0	0	0	16.7	0.7	0	0	0	0
Aquatic Prairie	0	0	0	0	0	0	0	0	0	0	0
Open Water	0	0	0	0	0	0	0	0	0	0	0
Shrubs	0	0	0	0	0.1	4.9	12.3	3.5	0	0	0
Scrub	0	0	0	0	0.5	9.8	0.2	0.2	0	0	0

Table 4-26 continued.

Vegetation Class in 1977	Upland Pine in 1990	Ogeechee-Cypress in 1990	Gum-Maple-Bays in 1990	Water Lily in 1990	Gum-Bay-Cypress-Shrub in 1990	Mixed Wet Pine in 1990	Sedges-Ferns-Water Lily in 1990	Briar-Shrubs in 1990	Bare Ground-Urban in 1990	Agricultur e-Lawn in 1990	Clearcut-Sparse Pine in 1990
Scrub-Shrub	0	0	0	0	0	16.4	0.7	0	0	0	0
Shrub-Pine	0	0	0	0	0	11.5	0	0	0	0	0
Shrub-Cypress	0	0	0	0	0	1.7	7.2	0.3	0	0	0
Shrub-Bay	0	0	0	0	4.3	45.7	0	0	0	0	0
Shrub-Prairie	0	0	0	1.0	0	0.4	7.1	0.1	0	0	0
Scrub-Pine	0	0	0	0	0	0	0	0	0	0	0
Scrub-Prairie	0	0	0	0	20.7	1.2	0	0	0	0	0
Total Class Area (ha) in 1990	0	0	0	18	26	467	253	25	0	0	0
% of Total Area in Class in 1990	0	0	0	0.4	0.5	9.1	4.9	0.5	0	0	0

Table 4-26 continued.

Vegetation Class in 1977	Aquatic Grasses	Open Water	Bay-Shrub	Cypress-Gum-Shrub	Loblolly Bay	Shrubs	Dense Pine	Sparse Pine	Mixed Upland-Wetland Shrubs	Pine-Cypress-Hardwoods	Total Class Area (ha) in 1977	% of Total Area in Class in 1977
Floodplain Area												
Upland Pine	0	0	1.1	12.7	10.4	0.4	13.2	13.6	2.9	25.0	860	3.7
Needle-leaved Evergreen	0	0	0	0	43.2	0	0	2.1	0	54.7	3	0.01
Bay	0	0	0.01	3.2	73.4	0	0.3	0	0.3	1.6	1087	4.7
Cypress	0	0	50.1	30.2	1.0	0.02	0	0	0	0	1530	6.6
Blackgum	0	0	0	11.8	44.9	0	0	0	0	0	225	1.0
Bay-Cypress	0	0	0.1	0.3	81.3	0	0	0	0	0	586	2.5
Mixed Cypress	0	0	9.7	21.2	32.9	0	0	0	0	1.1	1421	6.1
Cypress-Shrub-Prairie	0	0	45.4	41.3	3.4	0.02	0	0	0	0	1231	5.3
Mixed Pine	0	0	2.1	32.3	25.3	0	0.04	0.2	0	0.7	335	1.4
Herbaceous Prairie	0	0	21.5	33.0	13.3	0	0.1	0.2	0.3	0.5	1144	4.9
Aquatic Prairie	0	0	24.0	14.9	2.1	0	0	0	0	0.1	1843	7.9
Open Water	0	0	0	0	0	0	0	0	0	0	0	0
Shrubs	0	0	6.1	49.8	11.6	0.2	0.03	0	0	0.3	1318	5.6

Table 4-26 continued.

Vegetation Class In 1977	Aquatic Grasses	Open Water	Bay-Shrub	Cypress-Gum-Shrub	Loblolly Bay	Shrubs	Dense Pine	Sparse Pine	Mixed Upland-Wetland Shrubs	Pine-Cypress-Hardwoods	Total Class Area (ha) In 1977	% of Total Area in Class In 1977
Scrub	0	0	4.4	17.0	31.5	0	0.10	0.1	0.01	0.8	3558	15.2
Scrub-Shrub	0	0	5.5	36.8	24.5	0	0.5	0.2	0	0.1	1321	5.7
Shrub-Pine	0	0	17.7	6.1	25.9	4.4	4.7	0	0	17.5	67	0.4
Shrub-Cypress	0	0	7.7	36.8	32.3	0	0	0	0	0	535	2.3
Shrub-Bay	0	0	0.6	12.0	47.0	0	0.03	0	0	0.1	3849	16.5
Shrub-Prairie	0	0	9.6	33.7	17.6	0	0.2	0.5	0.4	0.2	1776	7.6
Scrub-Pine	0	0	0	0	0	0	0	0	0	0	0	0
Scrub-Prairie	0	0	4.3	39.5	5.8	0	0	0	0	0	646	2.8
Total Class Area (ha) In 1990	0	0	2753	5470	6217	9	133	135	38.0	310	23335	
% of Total Area In Class In 1990	0	0	11.8	23.4	26.6	0.04	0.6	0.6	0.2	1.3		
Cypress Creek Area												
Upland Pine	0	0	0	36.6	6.3	0	24.4	8.3	0	8.4	19	0.4
Needle-leaved Evergreen	0	0	0	0	0	0	0	0	0	0	0	0

Table 4-26 continued.

Vegetation Class in 1977	Aquatic Grasses	Open Water	Bay-Shrub	Cypress-Gum-Shrub	Loblolly Bay	Shrubs	Dense Pine	Sparse Pine	Mixed Upland-Wetland Shrubs	Pine-Cypress-Hardwoods	Total Class Area (ha) in 1977	% of Total Area in Class in 1977
Bay	0	0	3.3	30.9	2.9	0	0.3	0.2	0	1.5	136	2.6
Cypress	0	0	0	0	0	0	0	0	0	0	0	0
Blackgum	0	0	0	0	0	0	0	0	0	0	0	0
Bay-Cypress	0	0	0	0	0	0	0	0	0	0	0	0
Mixed Cypress	0	0	0	40.0	13.2	0	0	0	0	0	15	0.3
Cypress-Shrub-Prairie	0	0	70.4	29.5	0	0	0	0	0	0	122	2.4
Mixed Pine	0	0	0	88.6	0	0	0	0	0	0.7	20	0.4
Herbaceous Prairie	0	0	36.7	45.9	0	0	0	0	0	0	217	4.2
Aquatic Prairie	0	0	0	0	0	0	0	0	0	0	0	0
Open Water	0	0	0	0	0	0	0	0	0	0	0	0
Shrubs	0	0	24.7	52.9	0.1	1.6	0	0	0	0	583	11.3
Scrub	0	0	60.0	26.0	1.6	0	0.8	0.4	0	0.7	795	15.5
Scrub-Shrub	0	0	44.4	36.8	0.8	0.8	0	0	0	0	383	7.5
Shrub-Pine	0	0	0	88.5	0	0	0	0	0	0	25	0.5

Table 4-26 continued.

Vegetation Class in 1977	Aquatic Grasses	Open Water	Bay-Shrub	Cypress-Gum-Shrub	Loblolly Bay	Shrubs	Dense Pine	Sparse Pine	Mixed Upland-Wetland Shrubs	Pine-Cypress-Hardwoods	Total Class Area (ha) in 1977	% of Total Area in Class in 1977
Shrub-Cypress	0	0	57.1	33.6	0	0.1	0	0	0	0	640	12.5
Shrub-Bay	0	0	16.3	21.3	9.1	0	1.4	0.02	0	1.9	328	6.4
Shrub-Prairie	0	0	62.3	24.1	0	5.1	0	0	0	0	1838	35.8
Scrub-Pine	0	0	0	0	0	0	0	0	0	0	0	0
Scrub-Prairie	0	0	13.1	63.6	1.4	0	0	0	0	0	19	0.4
Total Class Area (ha) in 1990	0	0	2526	1626	54	107	16	5	0	16	5140	
% of Total Area in Class in 1990	0	0	49.2	31.6	1.1	2.1	0.3	0.1	0	0.3		

Table 4-27. Vegetation changes occurring during 1952-1977 in the floodplain area most likely affected by the sill's impoundment effects and the Cypress creek watershed. The 1977 map did not consist of grouped classes; values are % of the vegetation class in the 1952 map in the specified class of the ungrouped map in 1977. Minimum mapping unit for the comparison is 320 m.

Vegetation Class in 1952	Forested Upland Pine	Needle-Leaved Evergreen	Bay	Cypress	Blackgum	Bay-Cypress	Mixed Cypress	Cypress-Shrub-Prairie	Mixed Pine	Herbaceous Prairie	Aquatic Prairie
Floodplain Area											
Bare Ground-Urban	0	0	0	0	0	0	0	0	0	0	0
Wetland Forest	2.1	0	5.8	15.4	1.7	4.4	7.3	8.2	2.7	2.2	3.5
Prairie	0.1	0	0.2	2.9	0	0.1	1.8	11.6	0.1	24.3	31.0
Shrubs	2.8	0	4.4	0.9	0.8	0.3	5.8	0.2	0.8	1.4	2.6
Upland Pine	40.9	0.4	15.7	0	0	4.6	0	0	3.4	0.01	4.1
Open Water	0	0	0	0	0	0	0	0	0	0	0
Total Class Area (ha) in 1977	861	4	1085	1530	225	468	1253	1093	343	1061	1531
% of Total Area in Class in 1977	3.8	0.02	4.8	6.8	1.0	2.1	5.6	4.9	1.5	4.7	6.8
Cypress Creek Area											
Bare Ground-Urban	82.0	0	18.0	0	0	0	0	0	0	0	0

Table 4-27--continued.

Vegetation Class in 1952	Forested Upland Pine	Needle-Leaved Evergreen	Bay	Cypress	Blackgum	Bay-Cypress	Mixed Cypress	Cypress-Shrub-Prairie	Mixed Pine	Herbaceous Prairie	Aquatic Prairie
Wetland Forest	1.0	0	12.1	0	0	0	0	3.4	1.9	0.3	0
Prairie	0	0	0	0	0	0	0	0	0	0.6	0
Shrubs	1.9	0	0.4	0	0	0	0	0.4	0.01	0	0
Upland Pine	15.1	0	0	0	0	0	0	0	0	0	0
Open Water	0	0	0	0	0	0	0	0	0	0	0
Total Class Area (ha) in 1977	21	0	137	0	0	0	0	40	21	4	0
% of Total Area in Class in 1977	1.3	0	8.2	0	0	0	0	2.4	1.3	0.2	0

Table 4-27--continued.

Vegetation Class in 1952	Open Water	Shrubs	Scrub	Scrub-Shrub	Shrub-Pine	Shrub-Cypress	Shrub-Bay	Shrub-Prairie	Scrub-Pine	Scrub-Prairie	Total Class Area in 1952	% of Total Area in Class in 1952
Floodplain Area												
Bare ground-Urban	0	0	0	0	0	0	0	0	0	0	0	0
Wetland Forest	0	4.2	18.1	3.2	0.2	4.4	8.4	3.8	0	4.4	8852	39.6
Prairie	0	1.9	2.6	3.4	0	1.4	3.3	14.3	0	0.2	2991	13.4
Shrubs	0	8.3	17.6	9.7	0.2	0.8	30.6	10.2	0	2.6	9607	42.9
Upland Pine	0	5.6	13.1	0.5	3.1	0	7.4	0.9	0	0.3	924	4.1
Open Water	0	0	0	0	0	0	0	0	0	0	0	0
Total Class Area (ha) in 1977	0	1282	3491	1321	67	512	3848	1756	0	646	22374	
% of Total Area in Class in 1977	0	5.7	15.6	5.9	0.3	2.3	17.2	7.8	0	2.9		
Cypress Creek Area												
Bare ground-Urban	0	0	0	0	0	0	0	0	0	0	1	0.1

Table 4-27--continued.

Vegetation Class in 1952	Open Water	Shrubs	Scrub	Scrub-Shrub	Shrub-Pine	Shrub-Cypress	Shrub-Bay	Shrub-Prairie	Scrub-Pine	Scrub-Prairie	Total Class Area in 1952	% of Total Area in Class in 1952
Wetland Forest	0	0	36.9	17.2	0	10.0	14.4	2.7	0	0	1109	66.3
Prairie	0	0	8.1	0	0	10.8	0	80.5	0	0	115	6.9
Shrubs	0	0	26.1	28.5	0	11.5	29.2	1.9	0	0	447	26.7
Upland Pine	0	0	0	0	0	0	100.0	0	0	0	1	0.1
Open Water	0	0	0	0	0	0	0	0	0	0	0	0
Total Class Area (ha) in 1977	0	0	535	318	0	175	291	132	0	0	1673	
% of Total Area in Class in 1977	0	0	32.0	19.0	0	10.5	17.4	7.9	0	0		

increased during 1952-1977 and then remained nearly constant during the next 13 years, whereas shrub, prairie, and upland pine areas were nearly halved during 1952-1990 (Table 3-10). Prairie was replaced with wet forest and shrub. Upland pine increased during 1952-1977 and then decreased. These rates of change inside the sill impoundment impact area were less than those observed in the swamp overall during 1952-1977, and greater than those in the swamp overall during 1977-1990 (Table 3-11).

During 1952-1990 in the sill-affected Cypress Creek watershed area, most vegetation change was to wet forest, and more than half of the loss in prairie area was due to replacement by shrub (Table 4-24). Most of the shrub in 1990 in this area was composed of loblolly bay-shrub, and cypress-gum-shrub and mixed wetland pine (primarily slash pine and pond pine) made up the wet forest type (Table 4-25). The change to these types during 1952-1990 was primarily from scrub, scrub-shrub, shrub-bay, shrub-cypress, shrub-prairie, and cypress-shrub-prairie during 1977-1990 (Tables 4-26, 4-27). Prairie conversion in this area was primarily to bay-shrub and cypress-gum-shrub associations.

At least half of the changes occurring in the Cypress Creek watershed area occurred during 1952-1977. In contrast, most vegetation change in the remainder of the swamp occurred during 1977-1990, although most upland pine conversion occurred during 1952-1977 (Table 3-11). In the Cypress Creek area, prairie and upland pine coverage declined during 1952-1977 while shrub coverage increased. Wet forest declined by half during 1952-1990, and shrub coverage continued to grow during 1977-1990 (Table 3-10).

Discussion

The Okefenokee Swamp landscape has been affected by disturbance episodes of various types, intensities, and extents during the past 150 years. The responses to these disturbances have varied temporally and spatially. The overall structure of the landscape at the beginning and end of this 150 year period was relatively similar. Total proportions of the swamp area in wet forest, shrub, and upland forest associations have not changed, nor have the general locations of these communities in the landscape. Within this period shrub communities have been replaced by wet forest, prairie by shrubland and wet forest, and wet forest by shrubland and prairie. However, these changes are on a shorter temporal scale than the overall structural persistence of the system over the past 150 years. There has been some alteration in the species' compositions of these structural types, however. Although there are many areas that have returned to their pre-logging composition, there are other forested regions of the swamp where cypress and shrub-prairie were probably more abundant prior to logging and loblolly bay, loblolly bay-shrub, and blackgum-loblolly bay coverages have increased since logging occurred (Table 4-28). Some of this change resulted from the early 20th century logging. However, evidence suggests that disruption of the natural fire regime may also be driving this landscape evolution.

Cypress and pine were the predominant species logged from the swamp (Izlar 1984). Their return to the landscape has depended on the presence of a seed source,

Table 4-28. Vegetation changes occurring in Okefenokee Swamp during 1855-1990. Values are % of the prelogging vegetation in the specified class in each class during 1990. Minimum mapping unit for the 1990 map is 10 m; interpretation of the prelogging survey notes is on a much greater scale, from summarization of narratives and observation.

Prelogging Vegetation Class (1855-1890)	Upland Pine in 1990	Ogeechee-Cypress in 1990	Gum-Maple-Bays in 1990	Water Lily in 1990	Gum-Bay-Cypress-Shrub in 1990	Mixed Wetland Pine in 1990	Sedges-Ferns-Water Lilies in 1990	Briar-Shrub in 1990	Agriculture-Lawn in 1990	Bare Ground-Urban in 1990	Clearcut-Sparse Pine in 1990
Gum-Maple-Bays	0.01	0	0	0	55.3	0.1	0.1	0	0	0	0
Gum-Bay-Cypress-Shrub	0.01	0.02	13.6	0.1	22.5	1.5	1.1	0.5	0	0.2	0.01
Cypress-Gum-Shrub	0.1	0.1	0.9	0.7	15.1	3.2	6.0	2.1	0	0.02	0.01
Carex-Nymphaea	0.3	0	5.8	0	30.8	0	0.01	0	0	0	0
Wetland Pine	0.4	0.02	1.7	0.4	13.0	5.4	5.9	2.3	0.02	0.9	0.01
Pine-Palmetto	0.3	0.2	0.2	0.1	5.4	1.4	0.3	1.0	0.03	1.2	0.1
Oak-Hickory	0.1	0.01	4.5	0.02	22.2	0.4	0.1	0	0.01	0.2	0.1
Ogeechee-Cypress	0.1	0	0	0.1	1.2	24.5	1.7	2.1	0	1.3	0.04
Smilax-Shrub	0.1	0	0.1	2.0	6.1	2.5	12.1	5.2	0	0	0
Bays	0.02	0	0.3	0.3	29.3	0.4	3.8	1.0	0	0	0
Cypress-Shrub	0	0	0	0	0	0	0	0	0	0	0
Bay-Shrub	8.8	0	0	0	9.0	21.6	3.5	0	0	7.8	0.1

Table 4-28--continued.

Prelogging Vegetation Class (1855-1890)	Aquatic Grasses in 1990	Open Water in 1990	Bay-Shrub in 1990	Cypress-Gum-Shrub in 1990	Loblolly Bay in 1990	Shrubs in 1990	Dense Pine in 1990	Sparse Pine in 1990	Mixed Upland-Wetland Shrub in 1990	Pine-Cypress-Hardwoods in 1990
Gum-Maple-Bays	0	0	4.0	31.4	7.2	0.1	0.5	0.3	0	1.0
Gum-Bay-Cypress-Shrub	0.04	0	5.3	14.4	33.2	1.2	2.6	2.0	0.2	1.6
Cypress-Gum-Shrub	0.1	0.1	21.9	27.1	13.4	5.8	1.6	0.6	0.1	1.3
Carex-Nymphaea	0	0	1.2	10.3	50.0	0	0	0	0	1.8
Wetland Pine	0.1	0	17.1	24.6	9.2	6.4	6.0	2.9	0.2	3.4
Pine-Palmetto	0.3	0.01	4.2	6.6	3.5	1.0	29.2	25.4	5.4	14.2
Oak-Hickory	0.01	0	2.8	15.5	26.6	0.3	11.4	4.0	0.1	11.7
Ogeechee-Cypress	0.05	0	7.8	9.5	0	7.7	26.3	12.4	2.4	3.0
***Smilax*-Shrub**	0.03	0.04	25.6	30.6	2.2	12.7	0.4	0.1	0	0.4
Bays	0.03	0	17.2	27.4	18.2	1.9	0	0	0	0.13
Cypress-Shrub	0	0	0	0	0	0	0	0	0	0
Bay-Shrub	0	0	18.2	24.6	4.5	1.8	0	0	0	0

either from coppice growth (cypress) or water (cypress) or wind-dispersed (pine) seeds. Cypress seeds, like many woody wetland species, do not survive extended periods in the wetland seed bank (Demaree 1932), although they may survive submergence for up to a year (Applequist 1959). Since water flow is limited in much of the swamp to stream beds, most of the cypress regeneration distant to stream and river floodplains, where seeds are water dispersed, has probably occurred by coppice growth and local coppice production of seeds. Where these sources have been eliminated, cypress have also disappeared. Even where seeds have been available, the conditions for germination and seedling survival may have been limiting. Pond cypress's requirement of abundant light precludes it from areas already populated by shade-producing shrubs and trees (Terwilliger and Ewel 1986, Best et al. 1984, Hamilton 1984, 1982), and the seed's brief survival when submerged (3-12 months) eliminates it from establishing in areas with long hydroperiods following seed rain (Applequist 1959, Demaree 1932). Wetland pine (*P. serotina* and *P. elliottii*) was logged from sites with shorter hydroperiods and lower water depths, and replaced by bays, blackgum, and shrubs, to some extent a result of fire exclusion by humans. Again, seed dispersal and survival may have been a limiting factor as pine seed trees were removed, replaced by shade-producing shrubs, blackgum, and bays, and extended flooding occurred with impoundment near the sill (Pritchett 1979, Shriver and Fortson 1979). Once these competitors have become densely established, the possibility of cypress and pine reoccurrence depends on the additional factor of a severe fire which, as is discussed below, has not occurred in the swamp since logging occurred. Cypress and pine establishment did occur in some areas during and immediately

following logging. Terwilliger and Ewel (1986) and Ewel et al. (1989) reported highest densities of young pond cypress during the first few years following logging in North central Florida cypress domes. They also reported recovery of composition in logged domes within 45 years of logging; most of these domes had been selectively logged, and all showed evidence of recent burning. Neither of these factors are true for most of the Okefenokee Swamp forested areas.

Between the pre-logging period (1850-1890) and 1952 there was an increase in prairie, shrub, and upland pine communities and a decrease in wet forest coverage. This change was mostly due to revegetation by shrubs in sites that were forested prior to logging. Although individual shrub species can not be identified in the 1952 photographs, it is likely that by 1952 most of this shrub community was dominated by titi, with fetterbush, Virginia willow, and soapbush as secondary components; these species are colonizers of recently exposed peat and require short hydroperiods, low water depths, and high levels of light (Hamilton 1984, 1982, Deuver 1982, 1979, Cypert 1973, 1972, 1961). Other common shrub species in the swamp, such as hurrahbush and climbing fetterbush (*Pierus phillyreifolia*), are more shade tolerant and dominant in the forest understory, and probably did not occur in abundance in the 1952 communities where overstory growth was sparse. Loblolly bay, blackgum, and cypress seedlings may have already become established by 1952 in titi communities where sources of regeneration were available. Their presence could not be confirmed from the type and scale of photographs available for 1952, but subsequent remote sensing data from 1977 and 1990 indicate that these species were present in some areas occupied by shrubs in

1952, although not detected in 1952 as mature trees. By 1990 hurrahbush and climbing fetterbush were found in satellite image classification ground-truth plots (see Chapter 2) that contained gum-bay forest.

Between 1952 and 1977 nearly all of the swamp was burned by wildfires, and by 1977 most burned areas were replaced by shrubs, shrub-prairie, scrub-shrub, or wet forest. Proportions of prairie and upland pine remained constant during this interval; wet forest eliminated by fire was replaced by shrubs, primarily shrub-bay. In areas that were previously logged, replacement was equally by wet forest and shrubs by 1977, and prairie and upland pine to a much lower extent. The variety of wet forest and shrub types was much greater by 1977 than recorded during the pre-logging period. Although this might be an artifact of the pre-logging survey notes, resolution, and map, it probably also indicates the effect of the logging on the landscape composition. Large areas of relatively continuous vegetation types (probably densely canopied areas with shrub understory) were dissected by logging tramlines. In some area cypress remains only outside the scars, indicating that it was probably out of reach of the logging equipment. Revegetation in the logged portions to a different composition has probably increased the species complexity in those areas today. Logging introduced patches and edges where none previously existed, and created an edge type (that of a break in the forest canopy due to large-scale removal of trees) that previously had not occurred in the swamp, or occurred only after severe burning.

In most cases the wet forest association in a location during 1977 contained species also found in that area before it was logged; differences occurred primarily in

species dominance. This suggests that the source of regeneration was present after logging, but competitive interactions, site changes, and altered disturbance regimes may have affected the species composition in 1990. Thus, removal of the dominant wet forest species (primarily pond cypress, with some pond and slash pine in perimeter areas) by logging and modification of factors maintaining the system, such as the fire regime, have resulted in replacement by another species; where sufficient seed source remained and light was abundant, such as outside the logged area or at the logged fringe, the community probably more closely reflects the composition of the pre-logging era.

By 1990 the most common vegetation types in the swamp were cypress-gum-shrub, bay-shrub, and gum-bay-cypress-shrub, evolving from the shrub, scrub, and shrub-scrub dominated landscape of 1977 (Table 4-29). These associations occurred prior to logging, although cypress was dominate instead of bay and blackgum. The period 1977-1990 was notable for the numerous wildfires, which were quickly extinguished, and therefore were limited temporally, spatially, and in intensity. In the absence of severe fires, swamp communities have followed the successional sequences proposed by Hamilton (1982), and species requiring severe fire for maintenance are being replaced with those that thrive when fire is eliminated from the system (Figure 4-9). The fires that have occurred during the past 150 years have been litter-reducing, but have not been severe enough to cause long-term (i.e., century) changes in the swamp landscape structure, such as changing forests or shrubland to prairies or lakes. During the past decade of wildfire management, even these litter-reducing fires have been suppressed. This is permitting a fuel accumulation that could support an extensive, severe fire during

Table 4-29. Vegetation changes occurring in Okefenokee Swamp during 1977-1990. Values are % of the vegetation from the specified 1977 class changing to the specified vegetation type by 1990. Minimum mapping unit for the maps is 320 m.

Vegetation Class in 1977	Upland Pine in 1990	Ogeechee-Cypress in 1990	Gum-Maple-Bays in 1990	Water Lily in 1990	Gum-Bay-Cypress-Shrub in 1990	Mixed Wetland Pine in 1990	Sedges-Ferns-Water Lilies in 1990	Briar-Shrub in 1990	Bare Ground-Urban in 1990	Agriculture-Lawn in 1990	Clearcut-Sparse Pine in 1990
Upland Pine	0.4	0.1	0.2	0.02	3.6	1.3	0.3	1.2	0.8	0	0
Needle-leaved Evergreen	0	0	0	0	2.0	2.2	0.7	0	0	0	0
Bay	0	0	11.2	0	12.1	8.8	0	0.1	0	0	0
Cypress	0	0	0	0	8.3	0	5.0	5.3	0	0	0
Blackgum	0	0	33.5	0	12.4	0.1	0	0	0	0	0
Bay-Cypress	0	0	2.9	0	15.4	0	0.2	0	0	0	0
Mixed-Cypress	0	0	2.2	0.02	34.4	0.1	0.3	0.1	0	0	0
Cypress-Shrub-Prairie	0	0	0	0.03	6.8	0	9.0	0.7	0	0	0
Mixed Pine	0.1	0.04	0.4	0	17.7	1.4	0.4	0.1	1.3	0	0
Herbaceous Prairie	0	0	0.3	0.03	12.6	2.6	14.7	0.9	0	0	0
Aquatic Prairie	0	0.1	0	11.3	2.3	1.0	21.6	16.6	0	0	0
Open Water	0	0	0	0	0	0	22.4	0	0	0	0
Shrub	0	0	0.02	0.03	13.2	0.8	6.8	3.6	0	0	0
Scrub	0	0.01	1.8	0.01	17.9	2.7	5.8	0.4	1.01	0	0

Table 4-29--continued.

Vegetation Class in 1977	Upland Pine in 1990	Ogeechee-Cypress in 1990	Gum-Maple-Bays in 1990	Water Lily in 1990	Gum-Bay-Cypress-Shrub in 1990	Mixed Wetland Pine in 1990	Sedges-Ferns-Water Lilies in 1990	Briar-Shrub in 1990	Bare Ground-Urban in 1990	Agriculture-Lawn in 1990	Clearcut-Sparse Pine in 1990
Scrub-Shrub	0.1	0	0.1	0.02	9.0	2.2	9.0	1.1	0	0	0
Shrub-Pine	0.02	0	0	0.21	11.6	4.5	5.5	1.8	0.01	0	0
Shrub-Cypress	0	0	0.01	0.01	19.8	0.6	2.3	0.5	0	0	0
Shrub-Bay	0.4	0	1.3	0	27.3	5.8	0.5	0.02	0	0	0
Shrub-Prairie	0.01	0	0	0.13	6.6	0.8	10.6	2.1	0	0	0
Scrub-Pine	0	0	0.6	0	15.1	3.2	0.1	0.2	0	0	0
Scrub-Prairie	0	0.1	0.7	0.2	11.6	1.1	4.8	3.8	0	0	0

Table 4-29--continued.

Vegetation Class In 1977	Aquatic Grasses In 1990	Open Water in 1990	Bay-Shrub In 1990	Cypress-Gum-Shrub In 1990	Loblolly Bay In 1990	Shrubs In 1990	Dense Pine In 1990	Sparse Pine In 1990	Mixed Upland-Wetland Shrubs In 1990	Pine - Cypress-Hardwoods In 1990
Upland Pine	0.04	0	4.8	6.9	2.3	0.2	36.2	24.1	3.6	11.7
Needle-leaved Evergreen	0	0	11.7	28.5	3.5	1.0	18.6	4.6	3.7	4.7
Bay	0	0	0.6	8.9	56.2	0	0.6	0.3	0.1	1.0
Cypress	0	0	43.0	34.5	1.5	1.1	0.9	0.03	0	0.4
Blackgum	0	0	0.3	1.1	51.6	0	0.4	0	0	0.2
Bay-Cypress	0	0	0.4	2.3	78.2	0.2	0.2	0.21	0	0
Mixed-Cypress	0	0	7.7	19.2	34.6	0.03	0.3	0	0	0.8
Cypress-Shrub-Prairie	0	0	43.2	30.8	2.5	6.0	0.1	0.03	0	0.6
Mixed Pine	0	0	22.0	39.4	7.8	0.7	3.9	0.3	0	3.3
Herbaceous Prairie	0	0.4	22.4	36.7	6.8	2.2	0.03	0.1	0.1	0.1
Aquatic Prairie	0	0.2	24.1	18.5	0.3	3.9	0.01	0	0	0.1
Open Water	0	0	0	77.6	0	0	0	0	0	0
Shrub	0	0	23.8	38.9	5.5	6.0	0.6	0.5	0	0.5
Scrub	0.04	0	16.5	31.9	15.6	1.7	2.5	0.7	0.01	1.4

Table 4-29--continued.

Vegetation Class in 1977	Aquatic Grasses in 1990	Open Water in 1990	Bay-Shrub in 1990	Cypress-Gum-Shrub in 1990	Loblolly Bay in 1990	Shrubs in 1990	Dense Pine in 1990	Sparse Pine in 1990	Mixed Upland-Wetland Shrubs in 1990	Pine - Cypress-Hardwoods in 1990
Scrub-Shrub	0	0	25.7	37.7	6.7	5.4	1.2	0.4	0.1	0.9
Shrub-Pine	0	0	22.8	40.4	1.8	5.5	2.0	0.5	0	2.1
Shrub-Cypress	0	0	29.4	35.2	8.7	2.9	0.3	0.3	0	0.1
Shrub-Bay	0	0	7.5	20.8	34.9	0.6	0.6	0.1	0	0.3
Shrub-Prairie	0	0.2	34.1	29.7	4.3	9.8	0.6	0.1	0.03	0.6
Scrub-Pine	0	0	12.0	39.0	6.9	0.22	7.3	4.0	0.3	6.8
Scrub-Prairie	0	0	22.7	40.4	4.9	2.9	4.2	0.2	0	1.7

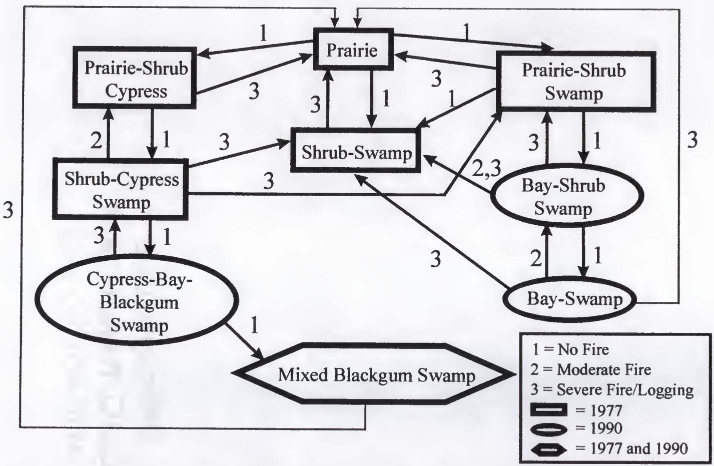


Figure 4-9. Dominant successional processes occurring in the Okefenokee Swamp landscape during 1977-1990. Although all vegetation types were present at both times, dominant community types at each time changed between years, as indicated by types in rectangles (1977) and ellipses (1990). Arrows and numbers indicate changes under various conditions. Greatest increase was in cypress-bay-blackgum. Mixed blackgum swamp was a minor type in both years (modified from Hamilton (1982)).

the next extended drought. The coupled effects of historic logging with this altered fuel load and fire regime are currently creating a landscape with similar structural appearance, but different species composition than the system present prior to logging. The predictability of the system's response to future wildfires will decrease as the landscape continues to evolve, driven by the altered disturbance regime and species composition. It is likely that a severe, extensive fire will burn during the next 50-100 years (Yin 1993) and alter much of the swamp landscape.

The Suwannee River Sill has extended hydroperiods and increased flooding depths in approximately 15% of the swamp (Chapter 3), primarily east and northeast of the sill. The Cypress Creek watershed (approximately 3% of the swamp) has also experienced an increase in water surface elevations, although it is unclear whether this is attributed directly to the sill or to other changes in the watershed drainage since sill construction. The sill's spatial effects are most extensive during high water periods; during low and average water depth periods water is impounded in a small area around the sill, and within the primary drainages. Most of the decrease in forest cover and increase in shrub and prairie cover in the sill impact area during 1952-1977 probably occurred during the wildfires of 1954-1955, and during 1960 when the marketable timber was removed from the area anticipated to be impounded immediately east of the sill. In the Cypress Creek watershed changes during 1952-1977 were from prairie and shrub to shrub-prairie and shrub-scrub types, following the 1954-1955 fires which burned primarily in prairie and shrub types. Expansion of forest and decline in shrub coverage during 1977-1990 occurred while the river floodplain area was almost continuously

impounded. There were occasional intervals during this period when the ground surface was intermittently exposed due to low precipitation or sill gate structural failure, permitting germination of cypress, blackgum, and bay seeds. The same trends were observed in the Cypress Creek watershed, where forest-shrub mixes replaced shrub-dominated communities. Stands of cypress and blackgum that established since the sill was constructed currently occur throughout the floodplain area impounded by the sill. Seedlings that developed into these stands probably survived flooding because they were dormant when it initially occurred, or they had attained sufficient height to tolerate extended flooding once it occurred. During 1993 and 1994, dry periods in the impoundment area extended long enough to allow establishment of cypress and blackgum seedlings that survived late season flooding. Although woody shrub species are present in the seed bank and might also germinate during these drawdowns, seed survival is probably low (see Chapter 7). Other than buttonbush (*Cephalanthus occidentalis*), those that do survive to germinate can not tolerate the long hydroperiods and deep flooding in the area east of the sill. Therefore, shrubs rooted in the ground probably have gradually been displaced from inundated sites in the river floodplain sill impoundment area, and only those on exposed stump surfaces, floating logs, and pond cypress buttresses have survived. Outside the floodplain region of the sill's impact, wet forest area is also gradually increasing while shrub coverage decreases. Cypress Creek watershed vegetation is following this trend. This displacement is occurring more rapidly inside the sill impact zone than outside, possibly because the extended hydroperiod and extreme water depths limiting germination of shrub species more

frequently occur, and established trees are tolerating these conditions. Recruitment of trees is sporadic, however, and probably occurs only during extreme, extended drawdowns. Throughout the swamp, vegetation succession is occurring in the absence of fire, away from fire maintained associations to those that flourish without fire; however, the driving functions differ. Hydrological manipulation is the controlling function in the sill impact area, whereas fire suppression is directing vegetation dynamics elsewhere.

Okefenokee Swamp vegetation changes occurring during the past 150 years suggests multiple scale processes that differentially affect the landscape structure and composition. The temporal and spatial effects of seasonal storms on swamp vegetation are small; severe wind creates localized disruptions in vegetation communities, with little effect on the landscape. Hurricanes have frequently passed over or near the swamp; unlike hurricane effects reported by Putz and Sharitz (1991) in bottomland hardwood forests in coastal South Carolina, accounts of widespread damage to Okefenokee Swamp vegetation have been infrequent during the past 150 years (C. Trowell, pers. comm.). Increasing abundance of bay species in the forested regions may increase the swamp's susceptibility to hurricane damage, however. Putz and Sharitz (1991) found greater damage to bottomland hardwood species rooted in elevated sites, and concluded that leaf size and permanency which creates wind resistence may also have made these species more prone to wind damage. Drought appears to have a greater potential effect than hurricane damage on Okefenokee Swamp vegetation composition and distributions. There appears to be a cycle of severe drought that probably occurs every few hundred years and lasts for several years (Yin 1993; Chapter 5 this volume). During these

infrequent but extreme droughts, wildfires are ignited and may burn across the entire swamp and cause temporally and spatially extensive changes in the swamp landscape composition (Cohen et al. 1984, Cohen 1975, 1974, 1973a, 1973b). Evidence in the peat suggests this occurred every few hundred years throughout the swamp since initial peat accumulation 6,500 years ago (Hermann et al. 1989, Cohen et al. 1984, Cohen 1975, 1974, 1973a, 1973b). Where these fires are sufficiently severe, new lakes and prairies might be created as trees and shrubs are killed and peat is burned. This is the hypothesized origin of several lakes and prairies present today (Cypert 1961, Hopkins 1947). Where they are less severe, communities undergo less extensive change, and recovery to pre-fire conditions probably occurs in a few years to decades, as has occurred in the Cypress Creek watershed.

Intermittent with these semi-century drought and fire cycles are less severe, less extensive fires that may not burn throughout the swamp (Yin 1993), and may be less spatially uniform in their severity. This results in fuel reduction in some areas and short-term structural or compositional changes to the landscape in other areas, and maintains the moving mosaic of communities in different developmental stages, similar in total composition to that present before burning. The fires that burned through the swamp during 1954-1955 and 1931-1932 were probably this type (see Hamilton 1982). In the absence of disturbance an area might change from prairie to forest within a century, with a regular series of succeeding species and associations determined by general site hydrological conditions, light availability, and propagule source (see Chapters 6, 7). When disturbance types that reduce or eliminate system variability are introduced, such

as logging, fire suppression, and impoundment, the system may become less resilient to successive disturbance events, and the type and scale of the system's responses may become unpredictable; a new stability domain may emerge as the system reorganizes (Holling 1995, 1986). It is possible that Okefenokee Swamp is currently responding to these types of disruptions with replacement of cypress-dominated forests with forests dominated by loblolly bay and blackgum.

Logging, which ceased 60-100 years ago, affected the swamp forest structure by removing trees and the seed source (primarily pond cypress in the swamp interior and pines in the uplands and swamp perimeter) and creating large areas suitable for shrub growth. Logged areas have frequently burned, and these fires may have been more severe where logging debris had accumulated; this may also have affected the subsequent species composition. Although areas where pond cypress was logged have since reforested, the composition has changed from pre-logging so that fire frequency and behavior and hydrologic processes (e.g., water flow, hydroperiod, evapotranspiration rates, etc.) have also probably changed. Recent alterations in the swamp fire regime due to wildfire management and use of controlled burns are probably also modifying the swamp landscape structure and composition, by suppressing the "mosaic maintaining" smaller fires as well as those that might burn throughout the swamp due to drought conditions.

Changes in the swamp landscape from prairie and shrubland to forest, and from cypress forest to bay-gum dominated forest, will remain unchecked if wildfire suppression continues, unless a large, hot, uncontrolled and uncontrollable fire occurs.

Shade tolerant, fire intolerant, and fire suppressing species are replacing cypress, which requires fire to remain in the landscape (Hamilton 1984, 1982, Best et al. 1984), may promote spread of fire by its features (e.g., shaggy bark, serotinous leaves and cones), and can survive fires that do not burn into the peat (Ewel and Mitsch 1978). This large-scale alteration in species composition in the landscape due to extensive early 20th century logging and disruption of the driving functions of fire and hydrology, may be reorganizing the swamp to a new stability domain. As the spatial variability of the landscape that gave the system resilience to extensive perturbations such as fire and drought disappears, an Okefenokee Swamp landscape will emerge that differs from that developing historically.

CHAPTER 5
FIRE IN OKEFENOKEE SWAMP

Introduction

Wildfire is integral to creating and maintaining certain vegetation communities. Effects of fire are over many spatial and temporal scales, with local to landscape-level responses occurring instantly and possibly continuing for years. Peat based wetlands are but one of several ecosystems that depend on periodic fires to shape the composition and structure of the landscape. Human-induced changes in community and landscape composition and structure potentially alter fire intensity and periodicity and affect the predictability of response to fire in these systems. Persistence of an ecosystem that evolved with and is naturally maintained by fire depends on maintenance of its natural fire regime. Without the fire disturbance, species are displaced with those that are better adapted to the changing conditions, and the successional sequence proceeds. If fire suppression is successful, a fire-dependent system ultimately can change into a system dependent on the absence of fire, and the intended protection actually leads to the system's demise. Environmental adaptations determine the suite of species that can exist in a landscape; their evolution to tolerate the existing and changing conditions and disturbances determines when a species appears and disappears from the landscape.

Although the culmination in a climax community rarely occurs across the landscape because of natural, restructuring disturbance events such as fire and drought, there is the potential to alter the composition of the interim communities and affect the predictability of the system's response, such as with artificial disruptions of hydrologic regimes or species composition due to logging. This disruption not only modifies the species composition but also can affect the behavior of the system in future disturbance events.

Evidence of fires in the Okefenokee Swamp exists from the oldest peat accumulated in the swamp interior (Cohen et al. 1984, Cohen 1975, 1973a, 1973b). Many of these fires probably originated in the swamp as lightning strikes and were eventually extinguished by saturated peat or precipitation. Their origin may also have been as lightning strikes in the perimeter longleaf pine (*Pinus palustris*), slash pine (*P. elliottii*), and wiregrass (*Aristida* spp.) communities, which are dependent on fire for establishment and maintenance (Hermann et al. 1989). With suitable weather conditions these fires could spread into the swamp matrix where they might be extinguished by saturated peat, or continue to burn into the swamp interior. Fire frequency varies spatially in the swamp. Throughout the swamp there is evidence of a large fire 6,000-10,000+ years ago, and intensive fires in 13 periods or roughly every few hundred years since then (Hermann et al. 1989, Cohen et al. 1984). Some areas, however, have no charcoal bands in the peat, suggesting they have escaped severe fire (Hermann et al. 1989, Cohen et al. 1984). Residents of the swamp area noted extensive drought and fires during 1838-1840, 1844, 1860, 1910, 1932, and 1954-1955 (Trowell 1987, Izlar 1984, Hopkins 1947). Many of these fires occurred during the spring months of March-May

during a drought following a severe freeze (Trowell 1987) and were extinguished by precipitation. Inhabitants of the perimeter uplands have frequently used fire to improve forage quality for livestock during the past few centuries. Indians occupying the area during the past 10,000 years were also known to use fire in land management (Trowell 1987, 1984a), although they had no ability to suppress fires ignited during droughts (Hermann et al. 1989).

Fire within the swamp has created landscape structure by removing areas of forest to form aquatic prairies, maintaining herbaceous and shrub prairies, and removing accumulated peat to create aquatic prairies and relatively deep depressions where lakes form (Cypert 1973, 1961). The last extensive fires responsible for substantial prairie initiation were probably in the mid-1800s (Cypert 1973, 1961, C. Trowell, pers. comm.), although small areas of prairie (each <200 ha) developed in the 1954-1955 burns (Hamilton 1984, 1982, Cypert 1973, 1961). The result throughout the swamp's history has been a moving mosaic in the landscape of vegetation communities, which become less dependent on maintenance by fire as they are removed from the effects of fire.

The usual sequence of swamp vegetation succession with peat accumulation is from aquatic prairie dominated by fragrant water lily (*Nymphaea odorata*) to herbaceous prairie of yellow-eyed grass (*Xyris* spp.), broomsedge (*Andropogon virginicum*), and sedges (*Carex* spp.), and in the absence of severe fire or extensive inundation, to titi (*Cyrilla racemiflora*) and eventually pond cypress (*Taxodium ascendens*) and swamp blackgum (*Nyssa sylvatica* v. *biflora*) forest (Hamilton 1984, 1982). The early successional species do not readily germinate and establish in shaded conditions, which

they create as they mature. Depending on the species, various hydrologic conditions are also required for establishment to occur (see Chapters 6 and 7). Fire occurrence and effect is decreased by extended hydroperiods; some areas of the swamp have always been aquatic and show no evidence of fire (Cohen 1973b). Inundation has always inhibited establishment of flood-intolerant species in these areas, except on elevated tree islands.

If absence of severe fire is prolonged, and effects of inundation are reduced by organic soil accumulation, the forest composition changes to shade tolerant species, such as fetterbush and hurrahbush, and cypress is accompanied by loblolly and sweet bay, and dahoon holly (Best et al. 1984, Hamilton 1984, 1982). As conditions become more shallow and shaded, cypress might be dominated by these hardwoods, which are less fire-tolerant and unlike cypress, have features that reduce fire susceptibility, such as sclerophorous leaves and smooth bark. Eventually only a severe, hot fire or mechanical removal of trees will permit invasion by earlier succession species (Hamilton 1984, 1982). Throughout the swamp the patchy distribution of vegetation types and evidence of past fire in the peat suggest that historically, fires were of variable size and intensity; their effects varied spatially due to the hydrologic environment and existing vegetation composition, and a shifting mosaic of communities has been maintained for at least 6,500 years (Cohen 1975, 1974, 1973a, Cohen et al. 1984).

Fires burned 114,935 ha of refuge and 60,705 ha of surrounding commercial and state land during 1954-1955 (Chapter 742, Public Law 81-810, 70 Statute 668). Although some of these incendiary and lightning-caused fires originated in the swamp and spread to the surrounding upland, many of the ignitions were on perimeter land, as landowners

set backfires to control the spread of fire away from the swamp and into the surrounding uplands (S.M. Reeves, pers. comm.). The severe drought conditions at the time enabled the upland and swamp fires to spread, burn into the peat, and remain active until precipitation extinguished the flames in June 1955. It was believed that had the Suwannee River been impounded at the time of these fires, the effects of the drought on the swamp would not have been as severe, the peat would have remained flooded, and the saturated peat would have extinguished the fires in the swamp before they spread into the perimeter. Additionally, protection from fire was viewed at the time as integral to the swamp's integrity. The sill, therefore, was intended to "protect the natural features and very substantial public values represented in the Okefenokee National Wildlife Refuge, Georgia, from disastrous fires and protect against damage from drought" (Chapter 742, Public Law 81-810, 70 Statute 668).

In addition to questions of the effects of the sill on the swamp hydrology addressed in Chapter 3 are questions of its effects on the swamp's natural fire regime. The sill is one of several fire control methods used by refuge staff. A perimeter road and fire break are maintained to arrest lateral fire movement. Active suppression of lightning strikes and incendiary fires, and a winter controlled burning program are also part of the refuge's fire management plan. Each of these management activities alters the natural fire regime by affecting fire periodicity, intensity, and spatial extent. These affects might be direct, as by impounding water and active fire suppression, or indirect by altering species compositions and therefore modifying fuel loads, moisture regimes, and fire susceptibility, or affecting the landscape structure with canoe trails and roads and thus

altering fire movement in the landscape. The actual contribution of the sill to its intended objectives must be discerned before deciding the sill's fate.

This chapter examines fire sizes, distributions, and frequencies during the period of available records, 1855-1993, and discusses effects of the current wildfire management activities on the swamp landscape. My objective was to determine whether changes in swamp vegetation distributions identified in Chapter 4 can be attributed directly to wildfire suppression or reduction caused by impoundment effects of the sill structure.

Methods

Wildfires and Prescribed Fires

The Okefenokee National Wildlife Refuge has maintained a wildfire occurrence log since the refuge was established in 1937. Prior to that date, fires were noted in regional newspapers, diaries of the area's inhabitants, and records of logging companies active in the swamp and perimeter (Trowell 1987). The multiple sources have resulted in records of varying content and quality. Information such as date, time, location, ignition source, fire size, and fire distribution maps are included in records of some fires; others note only general descriptions. Fire data used in this analysis included as many of these sources as possible. No doubt some fires were not recorded, or the information was overlooked while compiling data for this effort. The various sources also contribute a range of error. However, the spatial coverage database created from the available

records are believed to be generally representative of the overall wildfire history during 1855-1993, so that trends in fire occurrences and vegetation responses can be examined.

Descriptions of wildfires occurring prior to 1937 were taken from maps and documentation of Trowell (1987). He gathered most of this information from newspaper accounts and logging company records of fires in the area. The original, hand drawn maps in this documentation were not spatially referenced. The spatially referenced maps created for this analysis were screen digitized from these maps over the background of the registered, rectified, and merged 1990 SPOT satellite image. The tramline map Trowell 1994, 1983) (see Chapter 4) was also used to reference these fire locations. Digitized polygons of fire coverages were adjusted until the size was within 10 ha of the general burned areas estimated in Trowell (1987), or until the polygon appeared to approximate that in Trowell (1987) where sizes were not reported. Trowell's maps (Trowell 1987) were intended to show general location information of the fires and not actual acreage, so there may be error in these estimates due to uneven or incomplete burn. Therefore, they estimate maximum estimated burned area. Fire information from 1937-1993 was retrieved from refuge fire and biological reports and annual narratives. If fire maps were available, these were transposed onto 1966, 7.5" USGS 1:24,000 topographic quad maps and digitized to create wildfire coverages. Each fire year became a separate coverage, and if fire polygons overlapped in a single year, the coverage was divided to remove this overlap.

Some (22%) of the wildfire records, representing 2% of the estimated total area burned by wildfires during 1855-1993, included locations and size estimates but no

maps. Sizes of these fires ranged from 0.1 to 1011.8 ha. These fires were plotted as points using the location information for approximate placement, and then the points were buffered (surrounded) to create a circle with a radius that would result in the estimated burn area. This provided general fire location coverages for the wildfires without using actual reference maps. Although vegetation and topography were not considered in this approach, the method was believed to be acceptable given the small total acreage involved ($\bar{x}$ = 105.1 ha, range=0.01-1011.8 ha). Buffered points were saved as wildfire-year coverages unless wildfires in a single year overlapped; these were saved in multiple coverages for the year to spatially isolate each wildfire. Fire records (22) providing no size estimate or location were not mapped. Ignition source and date were recorded for all wildfires where available. All fires caused by humans, whether accidental or resulting from an escaped prescribed burn, were recorded as incendiary, since the distinction was not complete for all records; other causes of fire were lightning strikes or unknown.

Formal prescribed burn records were not kept by the refuge staff until 1973. Prior to this date there are anecdotal accounts of prescribed burns in the refuge records. A map and description were included if available, as for wildfires, for all prescribed burn records prior to 1973. The burn compartment, block, and unit designation were used for locating all prescribed burns following 1972. A compartment-block-unit designation was assigned to each prescribed burning polygon transposed from refuge hand-drawn maps to 7.5" 1:24,000 USGS quads. The dates of prescribed burns were added as coverage items,

so that the prescribed burn coverage contained all individual fires identified by burn year and month. Prescribed burn summaries are calculated from this coverage.

All spatial comparisons among wildfire coverages were made using ARCINFO (version 7.0, ERSI, Inc., Redlands, CA 92373) and IMAGINE (version 8.2, ERDAS, Inc., Atlanta, GA 30329) GIS analysis software. Fire polygons were converted to grids of 10x10 m cells using ARCINFO-GRID (ESRI 1992), and imported into IMAGINE (ERDAS 1995) for generating reports of each comparison among burn periods. Graphical comparisons in fire size and frequency were made to identify temporal trends.

Wildfire Occurrences and Vegetation Types

Distributions and compositions of swamp vegetation prior to logging around the turn of the century, and during 1952, 1977, and 1990 were examined in Chapter 4. Maps developed for the vegetation change analyses in Chapter 4 were compared with maps of areas burned during 1855-1993 to determine vegetation types that probably occurred where fires burned, to estimate the types of vegetation that resulted in the burned areas, and to determine if areas where vegetation change occurred were also where wildfires occurred. Fire maps were also compared with the tramline map developed in Chapter 4, to ascertain the association of wildfires with previously logged areas. Fuel loads at the time of each of the vegetation maps (1855, 1952, 1977, 1990) were also estimated using the fire behavior models of Anderson (1982) to compare available standing fuel (not peat) with fire sizes and numbers. Four models were used to estimate fuel amounts for different vegetation types prior to each of these periods. Time since last fire is not

considered in these models; the models provide estimates of burnable fuel relative to each vegetation type, but do not necessarily indicate how much will actually burn (Anderson 1982). The models can be used with weather and site condition information to make general predictions of fire severity. Fuel model values used for swamp fuel load calculations are listed in Table 5-1.

All spatial comparisons among wildfire and vegetation coverages were made using ARCINFO and IMAGINE GIS analysis software. Gridded fire polygons were imported into IMAGINE for generating reports of each comparison among burn periods and vegetation maps. Fire maps were similarly compared with the tramline map. Fuel load calculations were made with vegetation type-area calculations from the vegetation maps developed in Chapter 4.

Results

Fire Sizes, Frequencies, and Causes

During 1855-1993 approximately 96% of the swamp was burned by 249 wildfires. Approximately 302,079 ha burned during this period, much of it repeatedly, and 161,583 ha burned since the swamp became a National Wildlife Refuge in 1937. The largest fire was 115, 020 ha, which occurred during 1954-1955. This fire was actually a combination of several separate ignitions that merged into a common burned area. The average area burned by individual wildfires was 1017 ha; 81.5% of the fires

Table 5-1. Fuel models used in fuel load calculations, from Anderson (1982).

Vegetation Type	**Model**	**Total Fuel Load <7.6 cm[a], Dead and Alive (kg/ha)**	**Dead Fuel Load <0.64 cm (kg/ha)**	**Live Fuel, Foliage (kg/ha)**	**Fuel Bed Depth (m)**	**Total Fuel Load (kg/ha)**
Wet Prairie	3	6725.0	6725.0	0	0.76	5442.8
Cypress Forest	4	29141.7	11208.4	11208.4	1.83	20865.5
Shrub and Non-Cypress Forest	6	13450.0	3362.5	0	0.76	6803.5
Pine Forest	7	10984.2	2465.8	896.7	0.76	5828.3

[a] Fuel dimensions are for particle size or diameter.

burned less than 1% (1600 ha) of the swamp (Table 5-2). Prior to 1937 most wildfires were reported in March-July (Figure 5-1), and the largest fires began during April, June, and July (Figure 5-2). Other fires (excluding the large fires of 1931-1932) also burned in June and July (Figure 5-3). Following refuge establishment, the peak in burn area was in March, largely due to the 1954-1955 fires (Figure 5-4), and peak fire numbers occurred in June-August (Figure 5-5). If other fires (excluding the 1954-1955 fires) are considered after 1937, the peak in burn area appears to have shifted to July-November, with the most fires reported in July-September (Figure 5-6).

Lightning was the ignition source of 122 fires during 1855-1993, and 73 fires were known to be incendiary; 54 fires were of unknown origin. Since 1937 there have been 222 wildfires recorded in the refuge; 70 of these were known to be of incendiary origin, 111 were ignited by lightning strikes, and the sources of 41 fires are unknown (Figure 5-7). Lightning-caused fires occurred in March, May, and July, and incendiary fires in April during 1855-1937. Following refuge establishment in 1937 lightning fires were reported primarily during June-September, and incendiary fires occurred during all months, particularly January-June (Figure 5-7).

Frequency and seasonality of wildfires have not been uniform across the decades since refuge establishment. During 1938-1959 wildfires were reported during all months, and were most frequent in January and March-June. Excluding the fires of 1954-1955, the larger fires were in March-April and August-November. Most of these fires originated as lightning strikes (Figure 5-8). During 1960-1979 wildfires were reported in all but January, and were evenly distributed among months. Ignition source

Table 5-2. Summary of wildfires in the Okefenokee Swamp National Wildlife Refuge area, 1855-1993.

	1855-1993	**1855-1959**	**1960-1993**
Number of wildfires	249	98	151
Mean burn area (ha)	1379	3723	159
Variance of Burn Area (ha)	$1.1x10^7$	$2.9x10^7$	$1.1x10^5$
Maximum burn area (ha)	114935	114935	8407
Minimum burn area (ha)	0.04	0.1	0.04
Mode of burn areas (ha)	0.04	4.05	0.04
Number of lightning ignitions	122	33	89
Number of incendiary ignitions	73	30	43
Number of unknown source ignitions	54	35	19
Number of fires burning portions of swamp:			
<1%	203	62	141
1-4%	11	9	2
5-9%	2	1	1
<10%	216	72	144
10-24%	1	1	0
25-49%	1	1	0
50-74%	1	1	0

	1855-1993	1855-1959	1960-1993
75-95%	0	0	0
Number of fires with no area measurement	30	23	7
Number of unmapped fires	77	51	26
Mean area of unmapped fires (ha)	1737	135	64

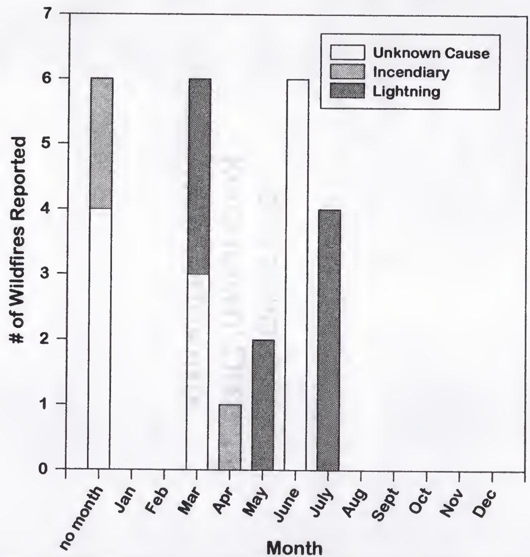


Figure 5-1. Number and cause of wildfires reported in the Okefenokee National Wildlife Refuge area during 1855-1936.

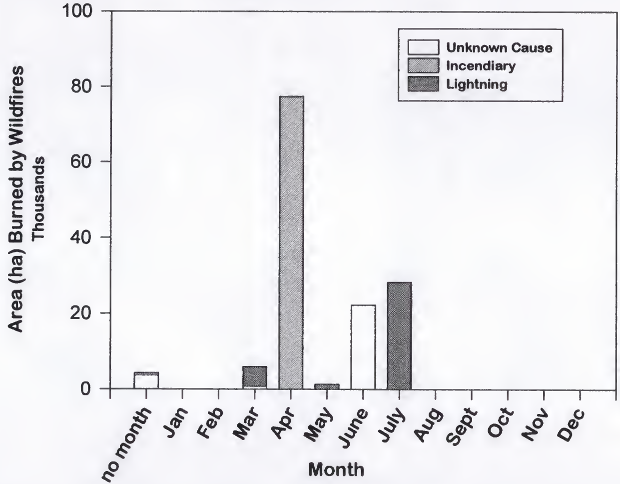


Figure 5-2. Total area burned in the Okefenokee National Wildlife Refuge area by wildfires during 1855-1936.

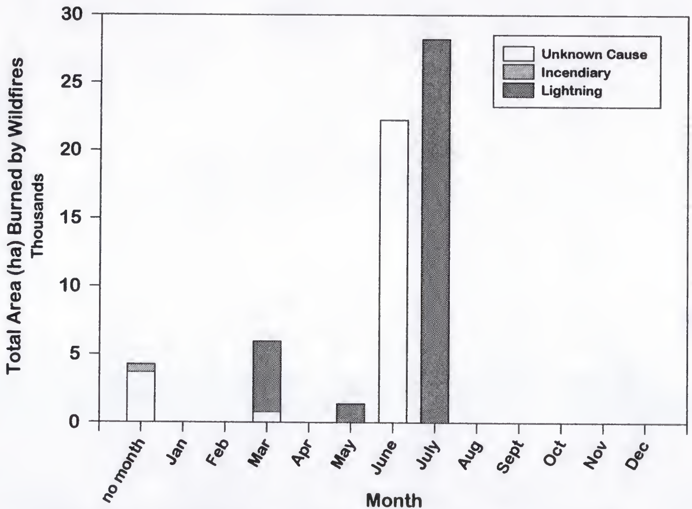


Figure 5-3. Total area burned by wildfires during 1855-1936, excluding the large fires of 1931-1932.

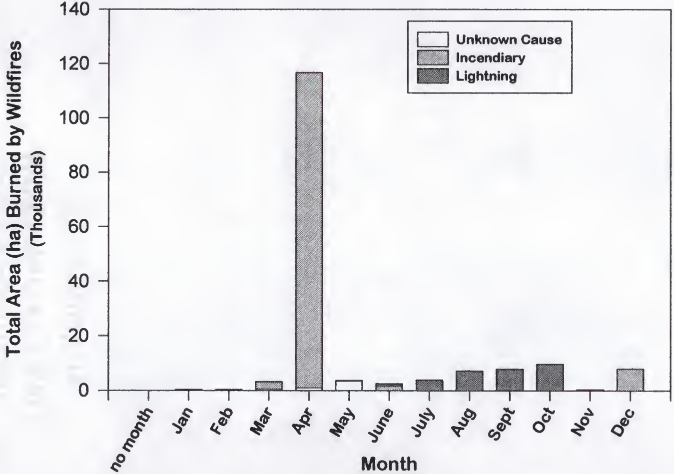


Figure 5-4. Total area burned in the Okefenokee National Wildlife Refuge by wildfires during 1936-1993.

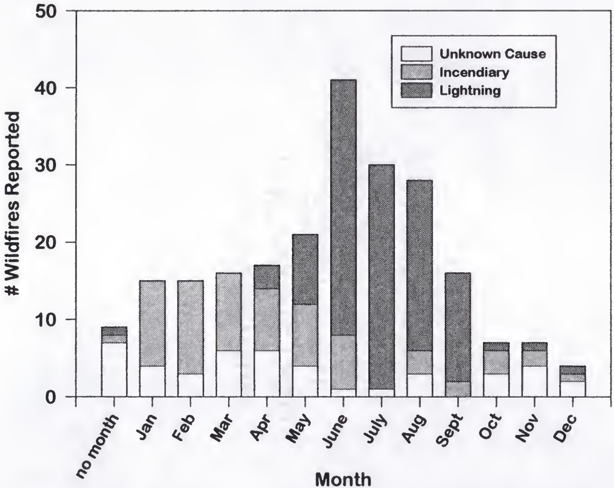


Figure 5-5. Number and causes of wildfires reported in the Okefenokee National Wildlife Refuge during 1937-1993.

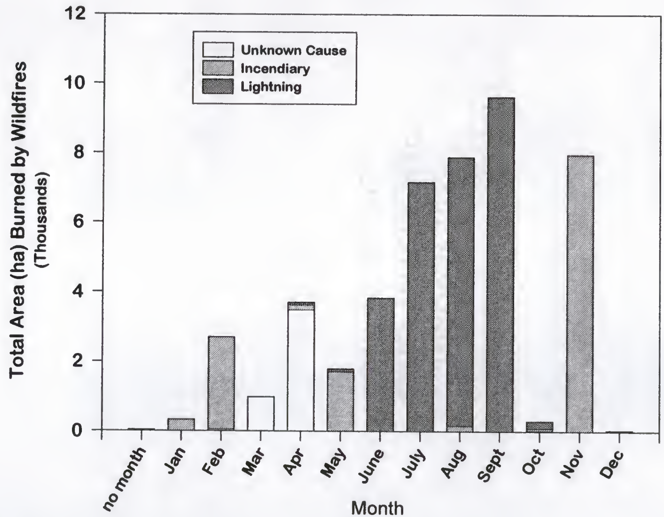


Figure 5-6. Total area burned by wildfires during 1937-1993, excluding those in 1954-1955.

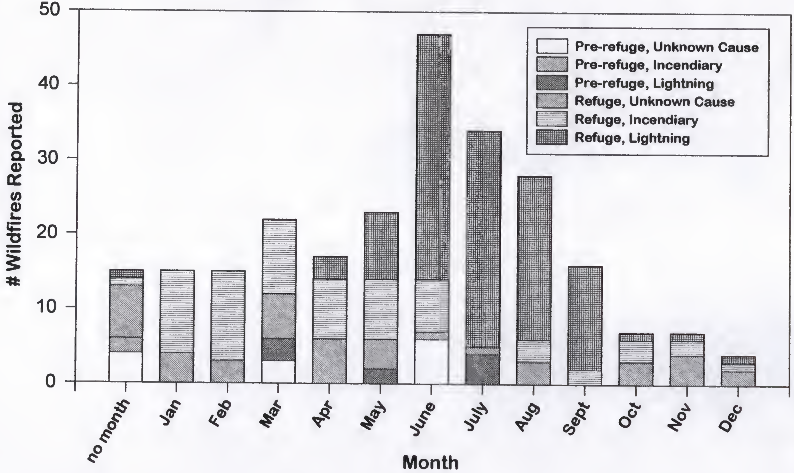


Figure 5-7. Number and causes of wildfires preceding (1855-1936) and following (1937-1993) Okefenokee National Wildlife Refuge establishment.

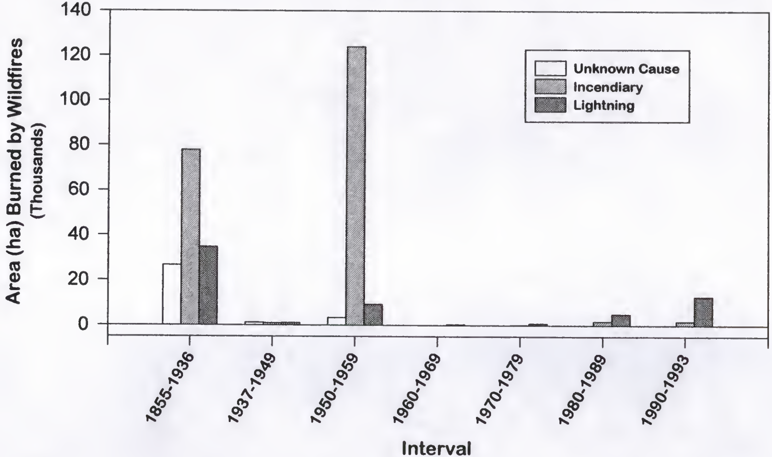


Figure 5-8. Total area burned and causes of wildfires occurring in Okefenokee Swamp by intervals during 1855-1993.

was predominantly lightning (59%) (Figure 5-9). Since 1980 wildfires occurred during all months at 2-10 times the frequency of early periods, and were most frequent during April and June-August. During 1980-1989 fire sizes were not as small as they had been during the 2 previous decades (Figure 5-10). By 1990-1993 wildfire size increased 2-5 times that of earlier decades. Ignition source for most wildfires during 1980-93 was lightning strikes (Figure 5-9).

The prescribed burning program intensified in the early 1970's. Although much of the upland areas were periodically burned prior to this date, the record is inconsistent until 1974. Since 1974 prescribed burning has occurred annually primarily in December-February on large islands and perimeter uplands (Figure 5-11). The prescribed burning season usually corresponds to periods of high water levels (Figure 5-12). Approximately 51,606 ha have been prescribed burned at various frequencies since 1953.

Vegetation Changes Where Fires Occurred

Most of the swamp burned during 1855-1952 (91%), and again in 1954-1955 (83%). Approximately 13% of the swamp has burned since 1955. Areas that burned in the swamp prior to 1952 were primarily in cypress-gum-shrub (shrub is a mix dominated by titi, hurrahbush, *Lyonia lucida*, fetterbush, *Leucothoe racemosa*, soapbush, *Clethra alnifolia*, and Virginia willow, *Itea virginica*) (38.9%), greenbriar (*Smilax* spp.)-shrub-prairie (primarily sedges, broomsedge, water lily, and chain fern, *Woodwardia virginica*) (34.6%), and gum-bay (loblolly bay, *Gordonia lasianthus*, sweet bay, *Magnolia virginiana*, swamp red bay, *Persea palustris*)-cypress-shrub (14.5%) (Table 4-18).

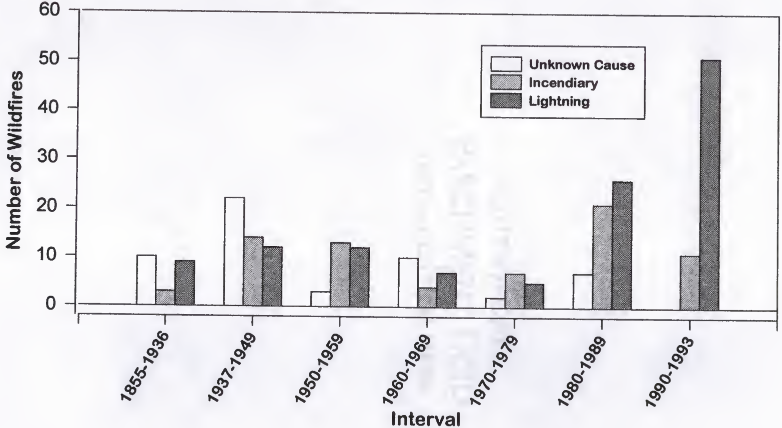


Figure 5-9. Number and causes of wildfires occurring in Okefenokee swamp during 1855-1993.

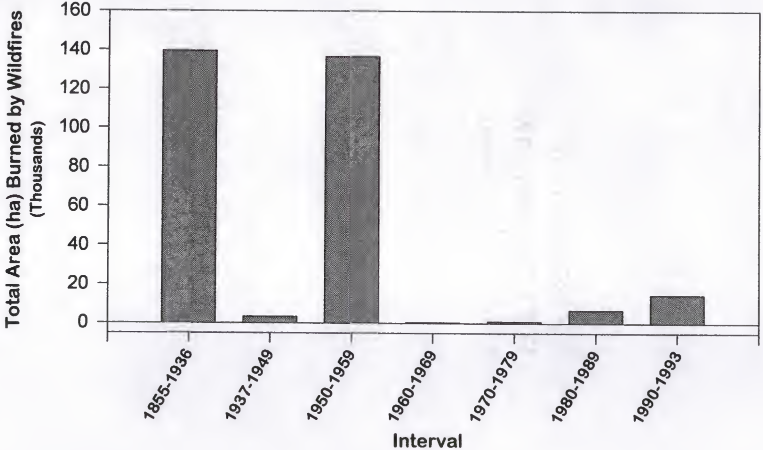


Figure 5-10. Total area burned by wildfires in Okefenokee Swamp during 1855-1993.

Figure 5-11. Prescribed burning compartments in the Okefenokee National Wildlife Refuge.

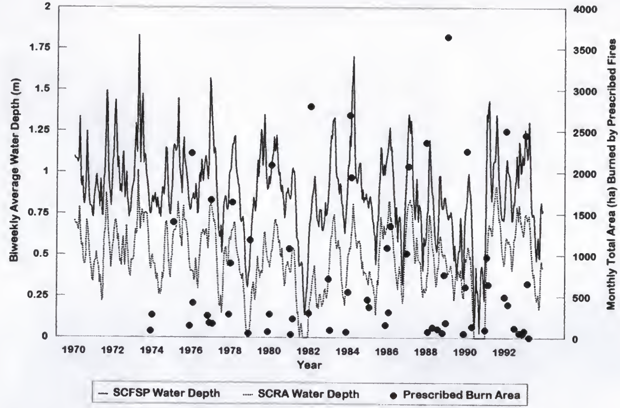


Figure 5-12. Water levels at Stephen C. Foster State Park (SCFSP) and Suwannee Canal Recreation Area (SCRA), and total prescribed burning area, during 1973-1993.

Revegetation in the burned areas by 1952 was primarily to wet forest (primarily slash pine, *Pinus elliottii*, pond pine, *Pinus serotina*, pond cypress, swamp blackgum, loblolly bay, sweetbay, and dahoon holly, *Ilex cassine*) (40%), shrub (41%), and prairie (14%) (Table 4-18).

The fires that burned in 1954-55 were the first widespread fires to affect the swamp following creation of the National Wildlife Refuge. Wet forest (38%), shrub (37%), and prairie (19%) communities were burned, and were replaced with shrub-prairie (17%), shrub (16%), prairie (16%), scrub-shrub (10%), scrub (8%), and a mixture of wet forest (8%) and shrub-forest (18%) types by 1977 (Table 4-22). By 1990 these areas had become bay-shrub (23%), cypress-gum-shrub (28%), sedges-ferns-water lilies (10%), shrub (10%), gum-bay-cypress-shrub (9%), and loblolly bay (6%) (Table 5-3). During the 36 years following the 1954-1955 fires, burning occurred primarily in the non-wetland parts of the swamp. Upland pine (primarily slash pine and longleaf pine, *Pinus palustris*) (57%), shrub-prairie (11%), shrub (9%), and cypress (7%) communities were burned, and by 1990 revegetated with upland pine (54%), pine-cypress-hardwoods (16%), cypress-gum-shrub (12%), and bay-shrub (10%) (Table 4-23). During 1990-1993 approximately 13% of the swamp burned. Most of the burned area contained communities of cypress-gum-shrub (34%), bay-shrub (27%), shrub (9%), and upland pine (10%) (Table 5-4). An intensive effort was made to extinguish wildfires during 1990-1993. Most of the area burned in 1990 and 1993 was by lightning ignition when water levels were low. The previous period of severe burning (1954-1955) also occurred during low water conditions, and the initial ignition source of those fires was lightning;

Table 5-3. Vegetation in 1990 in areas that burned during 1954-1955.

Vegetation Type in 1990	Percent of the Area that Burned in 1954-1955 that is the Specified Vegetation Type in 1990
Upland Pine (includes dense and sparse pine types)	5.0
Ogeechee-Cypress	0.01
Gum-Maple-Bays	0.5
Water Lily	1.5
Gum-Bay-Cypress-Shrub	8.9
Mixed Wet Pine	1.9
Sedges-Ferns-Water Lily	9.5
Briar-Shrub	4.1
Agriculture-Lawn	0
Bare-Urban	0.1
Clearcut-Sparse Pine	0.01
Aquatic Grasses	0.04
Open Water	0.05
Bay-Shrub	22.7
Cypress-Gum-Shrub	27.8
Loblolly Bay	6.1
Shrubs	9.6
Mixed Upland-Wetland Shrubs	0.5
Pine-Cypress-Hardwoods	1.7

Table 5-4. Vegetation that burned during 1990-1993.

Vegetation Type in 1990	Proportion of the Area that Burned during 1990-1993
Upland Pine (includes sparse and dense pine)	10.0
Gum-Maple-Bays	0.2
Water Lily	0.1
Gum-Bay-Cypress-Shrub	4.8
Mixed Wet Pine	2.4
Sedges-Fern-Water Lily	5.6
Briar-Shrub	0.6
Bare-Urban	0.1
Clearcut-Sparse Pine	0.01
Aquatic Grasses	0.02
Bay-Shrub	27.2
Cypress-Gum-Shrub	33.9
Loblolly Bay	1.3
Shrub	9.1
Mixed Upland-Wetland Shrubs	0.1
Pine-Cypress-Hardwoods	4.6

the first fire of the period was extinguished, but later incendiary and lightning-caused fires burned in spite of suppression efforts.

Fuel loads were estimated for swamp vegetation compositions in 1890 (representing the pre-logging period), 1952, 1977, and 1990. Peat is not included in these calculations, which consider only standing vegetation. Fuel volumes using the Anderson models (Anderson 1982) indicated a gradual increase since 1952, following a decrease between 1890 and 1952. A severe, intense fire followed 2 of these periods (1954 and 1990), and several fires occurred during 1855 to 1942, when commercial logging ceased. There were approximately $7.5x10^8$ kg of burnable fuels in the swamp in 1890, prior to logging activities. During 1855-1951 there were 65 wildfires reported. By 1952 the fuel volume had increased to $7.9x10^8$ kg, which decreased following the 1954-1955 fires to $4.6x10^8$ kg of burnable fuels in 1977, possibly as a result of the 1954-1955 fires. During 1952-1977 there were 54 wildfires that burned 137,170 ha. In 1990 the fuel load had increased again to $6.6x10^8$ kg, and from 1977-1993, 121 wildfires burned 21,549 ha. The composition of these fuels by vegetation type are estimated in Table 4-20. Fuel loads of prairies and upland pine communities were fairly constant among 1890, 1952, 1977, and 1990. Shrub fuel load was highest in 1977 and lowest in 1990. Wet forest fuel loads were highest in 1855 and 1990, and lowest in 1977. Wet forest area was composed of 55% cypress in 1855, and wet forest accounted for 79% of the fuel load. By 1977 cypress-dominated forest covered only 9% of the swamp area, but represented 23% of the total fuel load. In 1990 the cypress fuel load had increased to 60% of the total, and cypress covered 32% of the swamp area. Much of the cypress

forest in 1855 was replaced by non-cypress wet forest by 1990, although wet forest total fuel load was similar to that in 1855, when cypress dominated the wet forest area.

Vegetation Changes Regardless of Fire Occurrence

Changes in swamp vegetation were not dependent on the occurrence of fire. Overall proportions of changes in vegetation composition occurring during 1952-1977 were generally similar between areas burned and not burned during 1855-1952, 1952-1977, and 1977-1990 (Table 5-5). That is, the occurrence of vegetation changes during 1952-1977 was not necessarily dependent on fire occurring during 1855-1952, 1952-1977, or 1977-1990; similar transitions were indicated in the absence of fire as well as following burning (discussed in the previous section). Persistence of wet forest and shrub in 1952 and 1977 was not determined by burn history; however, compositions of these structural types differed between these periods. Most of the vegetation change that occurred in burned areas was from wet forest to shrub, or shrub to wet forest; types of changes in non burned areas were more varied (Table 5-5).

During 1977-1990 vegetation changes where burning had occurred in 1952-1955 were primarily shrub to cypress-blackgum-shrub or shrub to blackgum-bay-cypress-shrub (Table 5-6). This type of change also occurred in non burned regions, and persistent (i.e., never replaced by another vegetation type) wet forest was more common where burning had not occurred. Most of the fires in 1977-1990 were in areas of persistent upland pine. Where fires did not occur during 1977-1990, the primary type of vegetation change was from shrub to blackgum-bay-cypress-shrub . During 1990-1993 fire consumed areas that

Table 5-5. Types of vegetation changes in 1952-1977, and their proportions in area burned and not burned during 1855-1952, 1952-1977, and 1977-1990.

Vegetation Change Type, 1952-1977	% of Area Not Burned during 1855-1952	% of Area Burned during 1855-1952	% of Area Not Burned during 1952-1977	% of Area Burned during 1952-1977	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990
Bare Ground-Urban to Upland Pine	0.2	0.1	0.1	0.04	1.1	0
Bare Ground-Urban to Wet Forest	0.02	0	0	0	0.1	0
Bare Ground-Urban to Shrub	0	0.03	0	0	0.1	0
Bare Ground-Urban to Shrub-Bay	0	0.01	0.01	0	0.01	0
Bare Ground-Urban to Shrub-Cypress	0	0	0	0	0	0
Bare Ground-Urban to Cypress-Shrub-Prairie	0.03	0.01	0	0	0.1	0
Bare Ground-Urban to Scrub-Prairie	0.02	0	0	0	0.1	0
Bare Ground-Urban to Prairie	0	0	0	0	0	0

Table 5-5--continued.

Vegetation Change Type, 1952-1977	% of Area Not Burned during 1855-1952	% of Area Burned during 1855-1952	% of Area Not Burned during 1952-1977	% of Area Burned during 1952-1977	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990
Bare Ground-Urban to Open Water	0	0	0	0	0	0
Wet Forest to Upland Pine	1.6	0.5	0.9	0.6	2.8	0
Persistent Wet Forest	18.3	17.7	14.6	12.3	23.3	100.0
Wet Forest to Shrub	8.0	11.4	11.3	11.4	12.6	0
Wet Forest to Shrub-Bay	2.0	3.4	2.0	2.2	3.02	0
Wet Forest to Shrub-Cypress	1.7	4.0	5.7	2.8	2.6	0
Wet Forest to Cypress-Shrub-Prairie	6.5	2.4	1.2	6.7	1.6	0
Wet Forest to Scrub-Prairie	1.5	0.5	0.02	0.3	2.9	0
Wet Forest to Prairie	2.2	0.9	0.5	2.2	0.6	0
Wet Forest to Open Water	0	0	0	0	0	0

Table 5-5--continued.

Vegetation Change Type, 1952-1977	% of Area Not Burned during 1855-1952	% of Area Burned during 1855-1952	% of Area Not Burned during 1952-1977	% of Area Burned during 1952-1977	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990
Open Water to Upland Pine	0	0	0	0	0	0
Open Water to Wet Forest	0	0	0	0	0	0
Open Water to Shrub	0	001	0.1	0.02	0.01	0
Open Water to Shrub-Bay	0	0	0	0	0	0
Open Water to Shrub-Cypress	0	0	0	0	0	0
Open Water to Cypress-Shrub-Prairie	0	0	0	0	0	0
Open Water to Scrub-Prairie	0	0	0	0	0	0
Open Water to Prairie	0.03	0.03	0.07	0.03	0.1	0
Persistent Open Water	0	0	0	0	0	0
Prairie to Upland Pine	0.2	0.04	0.1	0.1	0.1	0

Table 5-5--continued.

Vegetation Change Type, 1952-1977	% of Area Not Burned during 1855-1952	% of Area Burned during 1855-1952	% of Area Not Burned during 1952-1977	% of Area Burned during 1952-1977	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990
Prairie to Wet Forest	0.7	0.7	0.3	0.6	1.1	0
Prairie to Shrub	1.9	4.3	4.9	4.1	4.8	0
Prairie to Shrub-Bay	0.3	0.2	0.2	0.3	0	0
Prairie to Shrub-Cypress	0.2	0.2	0.4	0.2	0.5	0
Prairie to Cypress-Shrub-Prairie	1.7	0.3	0.6	1.2	0.5	0
Prairie to Scrub-Prairie	0.2	0.03	0.2	0.03	0.34	0
Persistent Prairie	7.0	8.0	6.0	12.1	4.36	0
Prairie to Open Water	0	0.01	0.02	0	0	0
Shrub to Upland Pine	1.2	0.8	0.4	0.7	2.3	0
Shrub to Wet Forest	10.1	10.7	12.2	5.7	10.0	0
Persistent Shrub	13.5	17.2	20.4	18.2	12.0	0
Shrub to Shrub-Bay	7.0	6.5	5.3	5.4	1.7	0

Table 5-5--continued.

Vegetation Change Type, 1952-1977	% of Area Not Burned during 1855-1952	% of Area Burned during 1855-1952	% of Area Not Burned during 1952-1977	% of Area Burned during 1952-1977	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990
Shrub to Shrub-Cypress	1.5	1.7	4.1	1.0	1.8	0
Shrub to Cypress-Shrub-Prairie	3.3	1.3	4.3	2.4	0.8	0
Shrub to Scrub-Prairie	0.6	0.5	0.1	0.4	1.4	0
Shrub to Prairie	2.6	2.7	3.0	3.4	2.5	0
Shrub to Open Water	0	0	0.01	0	0	0
Persistent Upland Pine	3.6	3.2	0.7	4.6	3.4	0
Upland Pine to Wet Forest	1.9	0.5	0.8	0.8	1.4	0
Upland Pine to Shrub	0.3	0.1	0.02	0.2	0.2	0
Upland Pine to Shrub-Bay	0.2	0.04	0.03	0.1	0.01	0
Upland Pine to Shrub-Cypress	0	0.01	0.02	0	0	0
Upland Pine to Cypress-Shrub-Prairie	0	0	0	0	0	0

Table 5-5--continued.

Vegetation Change Type, 1952-1977	% of Area Not Burned during 1855-1952	% of Area Burned during 1855-1952	% of Area Not Burned during 1952-1977	% of Area Burned during 1952-1977	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990
Upland Pine to Scrub-Prairie	0.02	0	0	0	0.03	0
Upland Pine to Prairie	0.1	0	0	0	0	0
Upland Pine to Open Water	0	0	0	0	0	0
Total Area (ha)	82477	84214	42060	85161	25934	1878
Interpreted Area (ha)	32806	54770	17969	46116	11288	12

Table 5-6. Types of vegetation changes in 1977-1990, and their proportions in area burned and not burned during 1952-1955, 1977-1990, and 1990-1993.

Vegetation Change Type, 1977-1990	% of Area Not Burned during 1952-1955	% of Area Burned during 1952-1955	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990	% of Area Not Burned during 1990-1993	% of Area Burned during 1990-1993
Upland Pine to Bare Ground-Urban	0.1	0.04	0.1	0	0.1	0.04
Upland Pine to Wet Forest	0.7	1.0	0.8	5.2	0.9	1.9
Upland Pine to Open Water	0	0	0	0	0	0
Upland Pine to Prairie	0	0.03	0.1	0	0.02	0.1
Upland Pine to Shrub	0	0.4	0.01	0	0.5	0.03
Persistent Upland Pine	1.6	4.2	3.0	49.7	4.2	8.1
Upland Pine to Gum-Bay-Cypress-Shrub	0.2	0.2	0.04	0	0.2	0.3
Upland Pine to Cypress-Gum-Shrub	0.1	0.5	0.6	1.2	0.4	1.3
Upland Pine to Bay-Shrub	0.03	0.4	0.4	0.4	0.2	0.9

Table 5-6--continued.

Vegetation Change Type, 1977-1990	% of Area Not Burned during 1952-1955	% of Area Burned during 1952-1955	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990	% of Area Not Burned during 1990-1993	% of Area Burned during 1990-1993
Wet Forest to Bare Ground-Urban	0.01	0.02	0.1	0	0.03	0.02
Persistent Wet Forest	18.1	8.6	2.3	1.6	14.0	1.7
Wet Forest to Open Water	0	0	0	0	0	0
Wet Forest to Prairie	0.04	0.9	1.2	0.2	0.6	0.3
Wet Forest to Shrub	0.1	0.5	0.5	0.5	0.4	0.4
Wet Forest to Upland Pine	0.5	0.7	1.1	5.1	0.6	1.6
Wet Forest to Gum-Bay-Cypress-Shrub	7.5	4.1	0.7	0.1	6.3	1.3
Wet Forest to Cypress-Gum-Shrub	4.9	6.3	9.4	5.0	6.5	10.2
Wet Forest to Bay-Shrub	3.1	3.5	5.5	2.9	3.6	5.0
Shrub to Bare Ground-Urban	0	0	0	0	0	0

Table 5-6--continued.

Vegetation Change Type, 1977-1990	% of Area Not Burned during 1952-1955	% of Area Burned during 1952-1955	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990	% of Area Not Burned during 1990-1993	% of Area Burned during 1990-1993
Shrub to Wet Forest	4.6	2.4	1.3	2.9	3.1	1.2
Shrub to Open Water	0.1	0.01	0	0	0	0
Shrub to Prairie	3.1	3.3	5.4	0.1	2.4	3.7
Persistent Shrub	1.3	4.04	7.8	0.4	2.9	4.1
Shrub to Upland Pine	0.01	0.4	0.5	3.6	0.4	1.1
Shrub to Gum-Bay-Cypress-Shrub	7.8	2.9	0.5	0.8	4.1	0.5
Shrub to Cypress-Gum-Shrub	10.1	14.0	17.6	8.7	10.8	20.6
Shrub to Bay-Shrub	5.8	11.4	18.0	6.0	8.7	16.9
Shrub-Bay to Bare Ground-Urban	0	0	0	0	0	0
Shrub-Bay to Wet Forest	4.4	3.0	2.0	0	5.2	0.4
Shrub-Bay to Open Water	0	0	0	0	0	0

Table 5-6--continued.

Vegetation Change Type, 1977-1990	% of Area Not Burned during 1952-1955	% of Area Burned during 1952-1955	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990	% of Area Not Burned during 1990-1993	% of Area Burned during 1990-1993
Shrub-Bay to Prairie	0	0.1	0.1	0	0.02	0.02
Shrub-Bay to Shrub	0	0.1	0	0	0	0
Shrub-Bay to Upland Pine	0	0.1	0.1	0	0.1	0.1
Shrub-Bay to Gum-Bay-Cypress-Shrub	2.2	2.1	0.1	0	3.1	0.04
Shrub-Bay to Cypress-Gum-Shrub	0.8	1.8	0.8	0	1.3	0.2
Persistent Shrub-Bay	0.1	0.7	0.4	0	0.2	0.8
Shrub-Cypress to Bare Ground-Urban	0	0	0	0	0	0
Shrub-Cypress to Wet Forest	1.3	0.2	0.1	0	0.6	0.02
Shrub-Cypress to Open Water	0	0	0	0	0	0
Shrub-Cypress to Prairie	0.02	0.1	0.2	0	0.1	0.01

Table 5-6--continued.

Vegetation Change Type, 1977-1990	% of Area Not Burned during 1952-1955	% of Area Burned during 1952-1955	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990	% of Area Not Burned during 1990-1993	% of Area Burned during 1990-1993
Shrub-Cypress to Shrub	0.04	0.2	0.4	0	0.2	0.04
Shrub-Cypress to Upland Pine	0	0.02	0.1	0	0.01	0.1
Shrub-Cypress to Gum-Bay-Cypress-Shrub	3.7	0.3	0.04	0	1.2	0
Shrub-Cypress to Cypress-Gum-Shrub	3.7	1.0	1.6	0	1.3	1.7
Shrub-Cypress to Bay-Shrub	1.3	1.2	2.2	0	1.0	1.4
Cypress-Shrub-Prairie to Bare-Urban	0	0	0	0	0	0
Cypress-Shrub-Prairie to Wet Forest	0.6	0.1	0.1	1.5	0.2	0.4
Cypress-Shrub-Prairie to Open Water	0	0	0	0	0	0
Cypress-Shrub-Prairie to Prairie	0.3	0.5	0	0	0.04	0.03

Table 5-6--continued.

Vegetation Change Type, 1977-1990	% of Area Not Burned during 1952-1955	% of Area Burned during 1952-1955	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990	% of Area Not Burned during 1990-1993	% of Area Burned during 1990-1993
Cypress-Shrub-Prairie to Shrub	0.1	0.4	0.1	0	0.1	0.03
Cypress-Shrub-Prairie to Upland Pine	0	0.01	0.02	0.01	0.01	0.04
Cypress-Shrub-Prairie to Gum-Bay-Cypress-Shrub	1.6	0.1	0	0.04	0.4	0.01
Cypress-Shrub-Prairie to Cypress-Gum-Shrub	1.3	1.7	1.8	0.03	1.3	3.8
Cypress-Shrub-Prairie to Bay-Shrub	0.6	2.7	2.0	0	1.6	3.2
Scrub-Prairie to Bare Ground-Urban	0	0	0	0	0	0
Scrub-Prairie to Wet Forest	0.2	0.2	0.2	0.1	0.2	0.3
Scrub-Prairie to Open Water	0	0	0	0	0	0
Scrub-Prairie to Prairie	0	0.1	0.4	0	0.1	0.1

Table 5-6--continued.

Vegetation Change Type, 1977-1990	% of Area Not Burned during 1952-1955	% of Area Burned during 1952-1955	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990	% of Area Not Burned during 1990-1993	% of Area Burned during 1990-1993
Scrub-Prairie to Shrub	0	0.1	0.1	0	0.1	0.1
Scrub-Prairie to Upland Pine	0	0.1	0.2	1.5	0.1	0.3
Scrub-Prairie to Gum-Bay-Cypress-Shrub	0.03	0.2	0.1	0	0.3	0.2
Scrub-Prairie to Cypress-Gum-Shrub	0	0.9	1.9	1.4	0.8	1.6
Scrub-Prairie to Bay-Shrub	0	0.5	1.5	0.6	0.4	1.3
Prairie to Bare Ground-Urban	0	0	0	0	0	0
Prairie to Wet Forest	0.1	0.5	0.2	0.3	0.4	0
Prairie to Open Water	0.1	0.03	0.04	0	0.02	0
Persistent Prairie	1.8	3.5	0.9	0	1.9	0.2
Prairie to Shrub	0.7	2.1	1.2	0	1.0	0.1
Prairie to Upland Pine	0	0	0	0	0.01	0

Table 5-6--continued.

Vegetation Change Type, 1977-1990	% of Area Not Burned during 1952-1955	% of Area Burned during 1952-1955	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990	% of Area Not Burned during 1990-1993	% of Area Burned during 1990-1993
Prairie to Gum-Bay-Cypress-Shrub	0.8	0.5	0.3	0	0.7	0
Prairie to Cypress-Gum-Shrub	2.3	2.6	2.0	0	2.3	1.3
Prairie to Bay-Shrub	2.9	2.6	2.4	0.03	3.2	0.9
Open Water to Bare Ground-Urban	0	0	0	0	0	0
Open Water to Wet Forest	0	0	0	0	0	0
Persistent Open Water	0	0	0	0	0	0
Open Water to Prairie	0	0	0	0	0	0
Open Water to Shrub	0	0	0	0	0	0
Open Water to Upland Pine	0	0	0	0	0	0
Open Water to Gum-Bay-Cypress-Shrub	0	0	0	0	0	0

Table 5-6--continued.

Vegetation Change Type, 1977-1990	% of Area Not Burned during 1952-1955	% of Area Burned during 1952-1955	% of Area Not Burned during 1977-1990	% of Area Burned during 1977-1990	% of Area Not Burned during 1990-1993	% of Area Burned during 1990-1993
Open Water to Cypress-Gum-Shrub	0.01	0	0	0	0	0
Open Water to Bay-Shrub	0	0	0	0	0	0
Total Area (ha)	102223	132927	35583	1880	113664	13697
Interpreted Area (ha)	25981	130413	32884	1873	9106	13624

had been persistent upland pine or had changed from shrub to bay-shrub or shrub to cypress-blackgum-shrub during 1977-1990. These types of changes also occurred in areas that did not burn during that period.

Wildfire and Logging

During 1895-1942 nearly all of the marketable cypress, pine, bay, and blackgum were removed from the swamp interior and near perimeter uplands within the current refuge boundary (Table 5-7). Approximately 32682 ha (26%) of the swamp were logged.

Table 5-7. Composition of logging harvest during 1909-1927, from Hopkins (1947) and Izlar (1984).

Species	Volume (cubic meters)
Pond Cypress	1,842,771
Slash, Pond, and Longleaf Pine	555,651
Swamp Red Bay	2,552
Swamp Blackgum	284
Red Maple[a]	199
Live Oak[b]	199
White (Sweet) Bay	142
Sweetgum[c]	28

[a] *Acer rubrum*
[b] *Quercus virginiana*
[c] *Liquidambar styraciflua*

During and following the timber harvest, fires burned periodically in the swamp, frequently in the logged areas where logging debris had accumulated. During 1855-

1952, 23.0% of the area burned by wildfires was along previously logged tramlines; 64.2% of the logged area burned during that period (Table 4-21). The extensive fires of 1954-1955 burned in 79.8% of the previously logged area, which comprised 19.8% of the burned area in 1954-1955. The swamp did not burn extensively during 1956-1980; during this time only 1.0% of the swamp interior burned, and 43.0% of this area was previously logged. Of the area that burned in 1990-1993, 8.8% was previously logged; 5.7% of the logged areas burned during this period.

Before the area was logged, approximately 25% (1.94×10^8 kg) of the total standing fuel load in Okefenokee Swamp was in the tramline areas, which made up 26% of the swamp area (Table 4-19). Wet forest communities comprised 95% of this volume, and most (89%) of this was pond cypress. By 1990 the area previously logged contained approximately 1.3×10^8 kg of fuel; 80% of this was wet forest communities, and cypress trees made up 57% of the standing fuel. Non-cypress tree species contribution to the tramline area fuel load increased from 8% in 1855 to 23% in 1990. Shrub composition in the tramlines changed during 1855-1990; tramline area fuels were 2% shrub in 1855, 8% in 1977, and 13% in 1990. These trends follow the vegetation changes occurring outside of the logged areas, suggesting they are not exclusively the result of logging.

Recurrence of Fires

Large fires occur periodically in the swamp, but the majority of fires are small and burn less than 1% (1600 ha) of the swamp. Of the area burned in wildfires during 1855-1952 (particularly during the 1931-1932 fires), 74.1% burned again in 1952-1977,

and most of this occurred during the 1954-1955 fires (77.2%) (Table 5-8). Nearly all of the area that burned in 1977-1990 had burned in 1952-1955 (99.7%), and 71.5% had burned during 1855-1952. Areas that burned in 1990-1993 also burned in 1952-1955 (99.4%), and 41.5% burned in 1855-1952; only 1.8% burned during 1977-1990. There appears to be a 75-100 year burning return frequency for most of the swamp, and this 75-100 year fire consumes roughly 75% of the swamp. Fire recurrence is slight after this fire for 30-50 years, but if fire is permitted to occur, the burns will remain small (<10,000 ha) and less severe until appropriate weather conditions occur (drought) and the fuel load, which has accumulated for 75-100 years since the last large fire, is sufficient to perpetuate a large fire. Small fuel loads or non-drought conditions may carry less intense fires throughout the swamp, but changes in direction of vegetation succession are dependent on severe, hot fires which are more likely in drought conditions after fuel has accumulated. It is probably the combination of 30-year drought cycles and 75-100 year fuel accumulations that eventually converge to produce a large, hot fire that alters the landscape structure and creates the "moving mosaic" of communities within the swamp.

Fire Occurrence and Water Levels

Throughout 1941-1993 water levels at SCFSP and SCRA were negatively correlated with wildfire number and size (Table 5-9). Conditions under which wildfires occur in the swamp were fairly consistent during 1941-1993. There was a constant number of small fires occurring primarily during the summer months of 1941-1993. This corresponded to water level conditions which were dropping or low (Figure 5-13). The

Table 5-8. Proportion of burned areas that repeatedly burned.

Fire Year Interval	Area (%) that Burned in 1855-1952	Area (%) that Burned in 1952-1955	Area (%) that Burned in 1952-1977	Area (%) that Burned in 1977-1990	Area (%) that Burned in 1990-1993
Area that also Burned in 1855-1952 (%)	---	53.4	56.5	71.5	41.5
Area that also Burned in 1952-1955 (%)	77.2	---	100	99.7	99.4
Area that also Burned in 1952-1977 (%)	74.1	100	---	100	99.9
Area that also Burned in 1977-1990 (%)	8.9	5.4	8.5	---	1.8
Area that also Burned in 1990-1993 (%)	9.5	15.1	8.3	8.8	---

Table 5-9. Spearman rank order correlation comparisons (r_s, P) of wildfire size, water depths, and wildfire cause, for wildfires occurring during 1941-1993.

Interval and Parameter	SCRA Water Depth (m)	Burn Area (ha)	Total Number of Wildfires	Number of Lightning Ignitions	Number of Incendiary Ignitions	Control Burn Area (ha)
1941-1993						
SCFSP Water Depth (m)	0.8561 0.0001	-0.1559 0.0001	-0.1594 0.0001	-0.1477 0.0001	-0.0568 0.0428	0.1858 0.0001
SCRA Water Depth (m)		-0.1542 0.0001	-0.1528 0.0001	-0.1224 0.0001	-0.0750 0.0074	0.0894 0.0014
Burn Area (ha)			0.9297 0.0001	0.6020 0.0001	0.6205 0.0001	0.0341 0.2238
Total Number of Wildfires				0.6352 0.0001	0.6382 0.0001	0.0167 0.5516
Number of Lightning Ignitions					0.0187 0.5063	-0.0448 0.1104
Number of Incendiary Ignitions						0.0830 0.0030
1941-1959						
SCFSP Water Depth (m)	0.8929 0.0001	-0.1874 0.0001	-0.1801 0.0001	-0.1459 0.0018	-0.1090 0.0199	-0.0399 0.3949
SCRA Water Depth (m)		-0.1975 0.0001	-0.1979 0.0001	-0.1495 0.0014	-0.1091 0.0198	-0.0319 0.4966
Burn Area (ha)			0.8373 0.0001	0.3912 0.0001	0.6213 0.0001	-0.0220 0.6400
Total Number of Wildfires				0.5191 0.0001	0.6250 0.0001	-0.0262 0.5764
Number of Lightning Ignitions					-0.0333 0.4779	-0.0134 0.7757
Number of Incendiary Ignitions						-0.0165 0.7254

Interval and Parameter	SCRA Water Depth (m)	Burn Area (ha)	Total Number of Wildfires	Number of Lightning Ignitions	Number of Incendiary Ignitions	Control Burn Area (ha)
1960-1993						
SCFSP Water Depth (m)	0.8697 0.0001	-0.1754 0.0001	-0.1663 0.0001	-0.1827 0.0001	-0.0428 0.2222	0.1409 0.0001
SCRA Water Depth (m)		-0.1492 0.0001	-0.1364 0.0001	-0.1271 0.0003	-0.0636 0.0696	0.0800 0.0222
Burn Area (ha)			0.9771 0.0001	0.6801 0.0001	0.6226 0.0001	0.0346 0.3241
Total Number of Wildfires				0.6908 0.0001	0.6453 0.0001	0.0244 0.4868
Number of Lightning Ignitions					0.0394 0.2612	-0.0678 0.0531
Number of Incendiary Ignitions						0.1075 0.0021

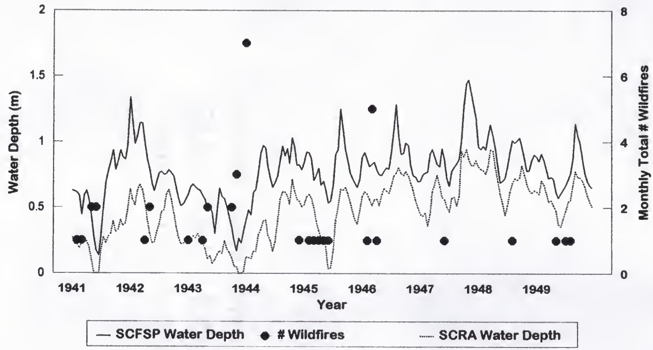
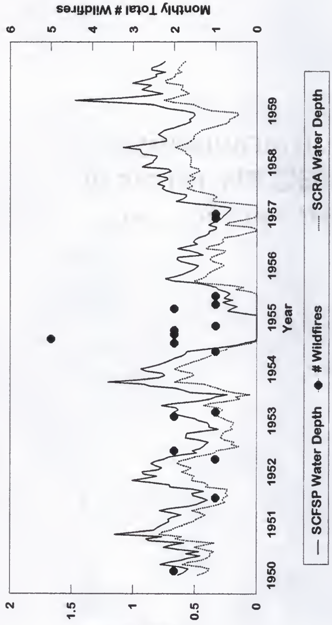


Figure 5-13. Water levels at Stephen C. Foster State Park (SCFSP) and Suwannee Canal Recreation Area (SCRA), and the number of wildfires reported monthly.



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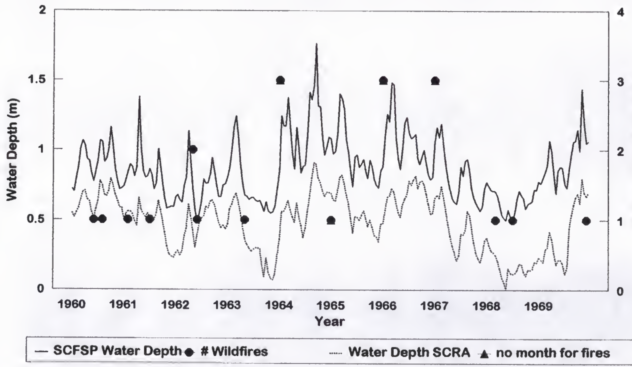

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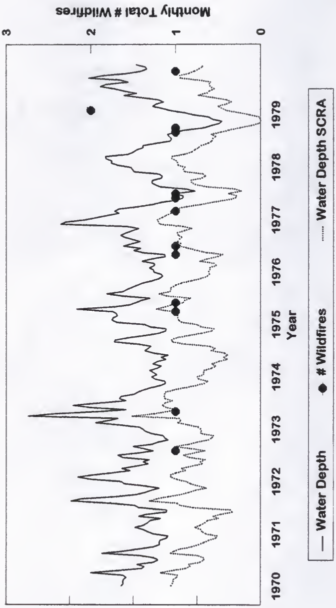

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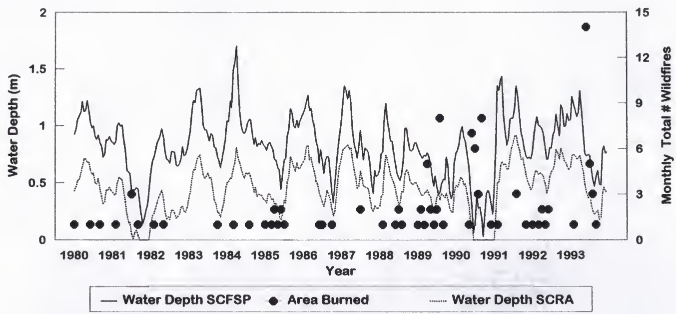


Figure 5-13--continued.

largest fires occurred when water levels were low or were increasing following a low period (Figure 5-14). During 1941-1959 the number of fires with incendiary or lightning ignitions was also correlated negatively with water level; number of incendiary fires was not significantly related to water level conditions during 1960-1993 (Table 5-9).

Most prescribed burns were carried out in upland areas during December-March, when water levels are usually high (Figure 5-15). Although a few of the incendiary fires originated as prescribed burns and accidentally spread, most of the prescribed burns were well-controlled. There has been an increase in prescribed burning area during the past two decades; acreage burned in prescribed fires exceeded that consumed in wildfires during 1970-1979 and 1980-1989 (Figure 5-16). However, the prescribed burning program has not replaced or displaced swamp wildfires. Most of the controlled burning was on interior islands and perimeter fire compartments composed primarily of upland and wet pine and upland shrub communities, rather than in the interior wetland types. Most of the wildfires occur during the summer months, when water levels are low; the refuge does little prescribed burning during this season due in part to fire hazard conditions which increase in the low water period. However, changes are occurring in the prescribed burning program to include more summer burns.

Fire and the Suwannee River Sill

During 1855-1993 there were 26 wildfires that originated in or burned into the area of the Suwannee River floodplain currently affected by the sill (Figure 5-17). Thirteen of these fires occurred after the sill was constructed (Figure 3-24). Ignition

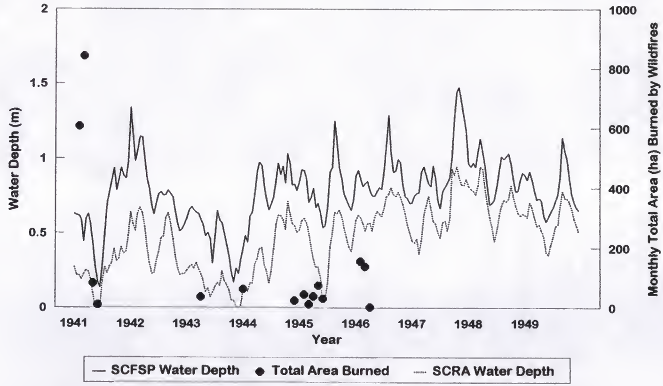
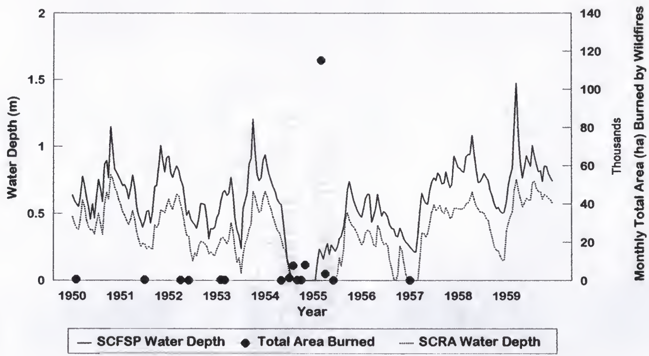


Figure 5-14. Water levels at Stephen C. Foster State Park (SCFSP) and Suwannee Canal Recreation Area (SCRA), and area burned by wildfires.



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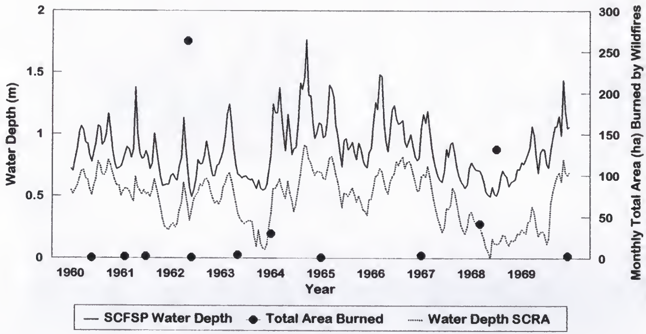

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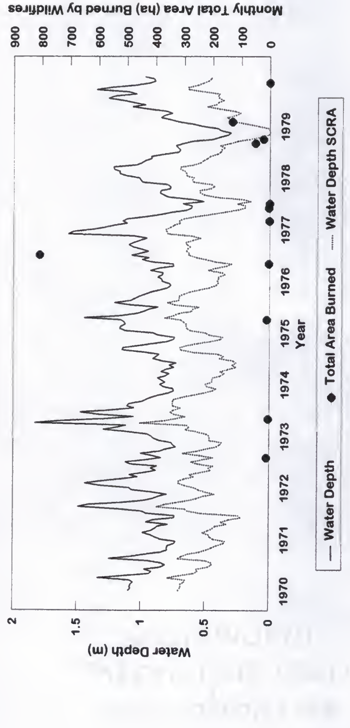

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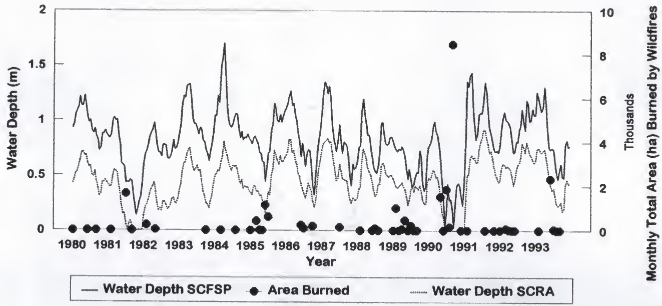

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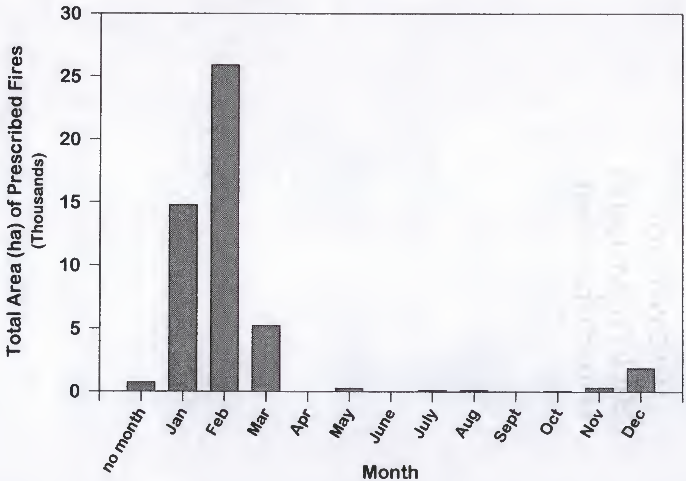


Figure 5-15. Total area of Okefenokee National Wildlife Refuge burned by prescribed fires during 1973-1993.

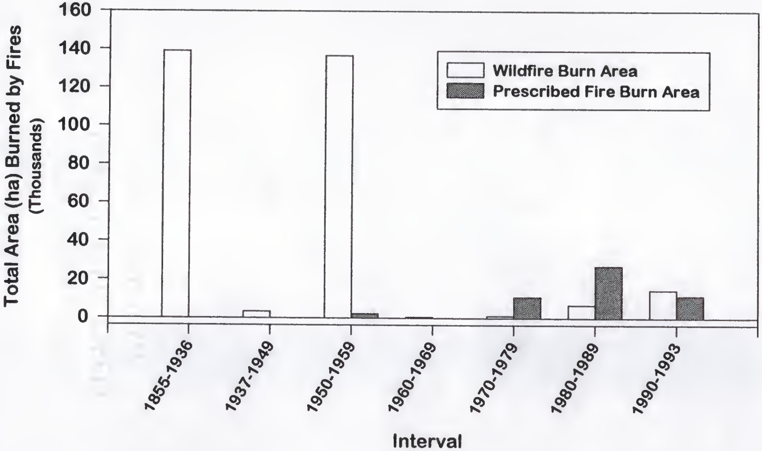


Figure 5-16. Total area of Okefenokee National Wildlife Refuge burned by prescribed fires and wildfires by intervals during 1855-1993.

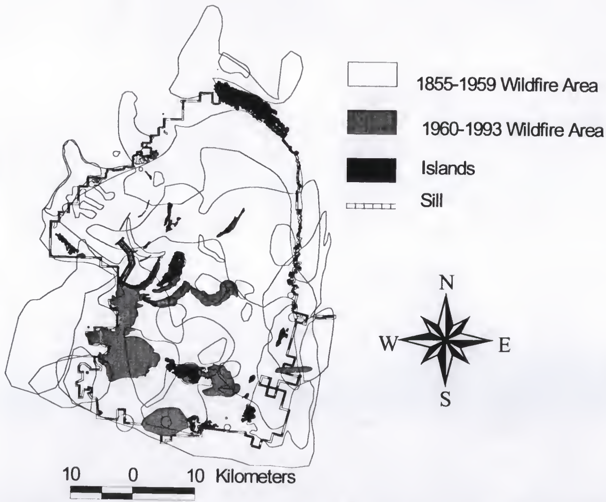


Figure 5-17. Locations of wildfires in Okefenokee National Wildlife Refuge, during 1855-1959 and 1960-1993. Extent of each fire is indicated by a black outline.

source of 20 of these fires was lightning; most (17) of these fires began in June-September. Drought conditions occurred when 17 of the wildfires burned in the sill area; water levels were low (3), average (2), or unknown (4) for the remainder. Eleven fires burned in the Cypress Creek watershed during 1855-1993; 6 occurred after the sill was constructed. In contrast to fires in the Suwannee River floodplain affected area, most of the Cypress Creek area fires were not lightning-caused. Those that were lightning ignitions occurred under low or drought conditions in June-September.

Wildfires burning into the Suwannee River floodplain area affected by the sill were smaller following sill construction ($\bar{x}$=122 ha, n=14) than before ($\bar{x}$=20246 ha, n=13). Although this suggests a decline in fire size due to the sill, that conclusion may be unfounded. The 4 largest fires burning into the area before 1959 were ignited outside the area of the future sill's influence during drought or low water conditions (Table 5-10). Drought or low water conditions occurred when 9 fires burned during 1855-1959 in the future sill's impact area. It is unlikely that these fires would have been arrested by the sill had it been in place; fires also burned in the area following sill construction when water depths dropped to low or drought levels throughout the swamp, and similar conditions occurred during the large fires before sill construction. Only 2 wildfires occurred in the area during 1941-1993 under average water level conditions; ignition sources for both of these fires were incendiary. These fires began to burn in upland areas (the Pocket and sill berm), and were extinguished by refuge personnel.

Wildfires in the Cypress Creek watershed also covered smaller areas following sill construction ($\bar{x}$=1374 ha, n=6) than before ($\bar{x}$=3133 ha, n=4 excluding the large fires

Table 5-10. Wildfires occurring in the Suwannee River floodplain and Cypress Creek watershed areas affected by the sill, water level conditions when the fires ignited, and the water level condition that would have been required to create impounded surface water and arrest the spread of these fires.

Fire Date	General Fire Location or Ignition Point[a]	Fire Size (ha)	Cause of Fire	General Water Level Conditions in Swamp	Sill-Affected Zone[b]
Floodplain Area					
1874	Suwannee Canal logging Tramline	480	lightning	unknown	high
1915	Sill area logging tramline	770	lightning	unknown	drought
July 1931	Southwest of sill area	18643	lightning	drought	low
April 1932	North half of sill area to Billy's and Floyd's Islands	77364	incendiary	drought	drought
10 June 1941	Tip of Pocket	10	lightning	drought	low
6 April 1943	Pocket Area	36	lightning	drought	drought
8 June 1945	Southeast of Rowell's Island	30	lightning	low	low
14 April 1952	Billy's Island	61	incendiary	very low	low
6 July 1954	Billy's Island	1405	lightning	drought	low
19 August 1954	Pocket tip	5	lightning	drought	low
20 August 1954	South end of Pocket	<1	lightning	drought	drought
4 September 1954	West of sill	8	lightning	drought	low

Fire Date	General Fire Location or Ignition Point[a]	Fire Size (ha)	Cause of Fire	General Water Level Conditions in Swamp	Sill-Affected Zone[b]
5 March 1955	Everything south of Sapling Prairie	164380	incendiary	drought	drought
10 May 1963	Pocket	4	unknown	very low	drought
21 March 1968	Sill dike, Pine Island	89	incendiary	average	drought
3 October 1983	Pocket tip	<1	incendiary	average	low
6 June 1985	Pocket	1174	lightning	drought	drought
27 June 1988	Between Hickory and Palmetto Islands	2	lightning	drought	drought
10 August 1989	NW of Floyd's Island	<1	lightning	drought	high
10 August 1989	NW of Floyd's Island	<1	lightning	drought	high
1 September 1990	West of Pocket	26	lightning	drought	drought
3 September 1990	Pocket tip	<1	lightning	drought	low
5 September 1990	West of sill	1	lightning	drought	low
10 September 1990	West of sill	<1	lightning	drought	low
8 August 1991	SE of Floyd's Island	<1	lightning	drought	high
4 August 1993	E of Floyd's island	<1	lightning	drought	high
5 September 1993	East of Minnie's Island	405	lightning	drought	high

Fire Date	General Fire Location or Ignition Point[a]	Fire Size (ha)	Cause of Fire	General Water Level Conditions in Swamp	Sill-Affected Zone[b]
Cypress Creek Area					
June 1927	Cypress Creek	8152	lightning	drought	
July 1931	Cypress Creek and West	3743	lightning	low	
17 February 1941	SW Sapp Prairie	607	incendiary	low	
31 October 1954	SW Strange Island	30	incendiary	drought	
5 March 1955	throughout watershed	164380	incendiary	drought	
27 September 1980	SW Sapp Prairie	10	incendiary	low	
27 July 1987	East of Cypress Creek	12	lightning	average-low	
31 March 1989	SW Sapp Prairie	2	incendiary	average	
10 August 1989	Sapp Prairie	<1	unknown	low	
October 1990	NW Sapp Prairie	8217	lightning	drought	
27 December 1990	SW Sapp Prairie	4	incendiary	low-drought	

[a] See Figure 2-1 for map of place names.
[b] Sill Affected Zone refers to the region of the swamp near the sill that is impounded by the sill in high, low, and drought water level conditions (Figure 5-18). The Cypress Creek watershed is included in entirety for all water levels.

of March 1955). Only one fire, of incendiary origin, occurred during average water level conditions; drought or low water conditions occurred when the other fires ignited. The incendiary fires which burned in the area with and without the sill also occurred during low or drought conditions. This area retains water during periods of abundant precipitation, but when precipitation is limited, conditions approach pre-sill levels. During high water level conditions since sill construction, this area may actually de-water more rapidly than prior to sill construction. The greater difference between water levels in the creek watershed and the river below the impounded water at the sill facilitates more rapid draining of the creek (see Chapter 3). This difference and the rate of creek drainage decreases with declining swamp water levels. Most wildfires are ignited by lightning strikes during June-September, when water levels are falling due to high levels of evapotranspiration. Thus the sill impoundment effects in this area occur primarily when wildfire potential is low.

Although the sill may provide fire protection under a limited range of water level conditions, its performance is not perfect. Areas in the Suwannee River floodplain and Cypress Creek watershed impounded by the sill during various water level conditions are delineated in Figure 3-24. Following sill construction four fires occurred during drought in the floodplain region that probably was impounding water, but only within the river and stream beds. Three wildfires occurred during drought in the floodplain area that had the potential to contain some impounded water during low water conditions, but not necessarily during drought conditions. In the area impounded in the floodplain only under average to high water level conditions, one fire occurred during drought. One fire

occurred under average water level conditions in the area that is impounded during low water conditions. These fires were extinguished before burning more than 400 ha. Because of generally low water level conditions when these fires occurred, it is possible that they would have had a much greater spatial extent if permitted to burn, in spite of the presence of the sill, because the extent of the impounded water was most likely limited to the river and stream beds. Wildfires in the Cypress Creek watershed also burned during low water level conditions; although fire suppression efforts controlled several of these fires, the largest burned until extinguished by precipitation.

Discussion

Determining the impacts of the Suwannee River sill on the Okefenokee Swamp hydrology and vegetation requires that the "natural" successional sequences and disturbance patterns be recognized, as well as the effects of man-induced processes that have affected the landscape in the past, such as logging, draining, peat mining, and fire control. Only when all of these effects are assessed simultaneously can the impacts of the sill on the current hydrologic environment and vegetation communities be assessed. There have been changes in the Okefenokee Swamp vegetation composition during the past 40 years that indicate the system is becoming more forested than in its recent past; examination of the history of these trends suggests that logging and fire suppression have contributed to these changes.

There were 2 periods since the early 1900s when most of the swamp was burned by wildfires. Both of these fire periods included lightning and incendiary fires, and occurred during droughts. However, even though most of the swamp was burned, the vegetation composition changed only in a small proportion of the burned area (Hamilton 1984, 1982, this study Chapter 4). This finding suggests that the fires were not severe, although they were extensive. Evidence of extensive, historic fires exists in the peat; during the past several thousand years, forest communities existed where prairies occur today and prairies existed in currently forested areas (Cohen et al. 1984, Cohen 1975, 1974, 1973a, 1973b, Fearn and Cohen 1984, Rich 1984a, 1984b, 1979). Response to the 1954-1955 fires indicate that a forested area requires intensive burning repeatedly over a few to several years to result in a prairie, or a fire needs to be hot enough to remove peat and kill roots buried in the peat or underlying sand to revert a shrub or forest stand after a single fire to prairie or open water (Hamilton 1984, 1982, Cypert 1973, 1961). The fact that this kind of change occurred in less than 5% of the swamp after the 1954-1955 fires indicates that the area has not been recently affected by a wildfire that was severe enough to alter succession for more than a few years. Alternatively, the extent of severe fires may be only local, but if they occur frequently, they may ultimately create more structure and texture in the landscape than infrequent, extensive, but low intensity fires.

The change in the annual peak wildfire frequency from March-July to June-August, and change in peak burn area from July-November to June-August, may be attributed to several factors. The shift in fire season may be an artifact of better reporting of lightning strike fires under the recent (since 1974) fire management program. There is

also the possibility that the accumulation of fuel has reached levels that will easily carry wildfire if an ignition occurs when water levels are low, which occurs primarily in the late spring and late summer months. Late summer also corresponds to the peak in lightning strikes. These fires have the potential to get large and severe if water levels are low (Yin 1993), since the approaching fall is usually accompanied by decreasing precipitation and therefore lower water levels. It is these fires that would probably be the most effective in maintaining or changing the swamp landscape, since they accompany seasonal drought.

The prescribed burning program is concentrated in the winter months, when ignitions of wildfires are low, and is focused on the perimeter and interior upland communities. These areas support slash and longleaf pine communities that benefit from the frequent burns, but they represent a small portion (8%) of the total refuge area. In the swamp interior the threat of damage to refuge structures, perimeter private property, increased fire suppression costs as the fire grows, and danger to visitors restricts the use of prescribed fire and prompts suppression of wildfires while they are still small and controllable, frequently when allowing them to burn would be most beneficial to the swamp landscape. The expense of managing and fighting a wildfire grows exponentially with its size; this financial burden must be considered in wildfire management, so that the decisions made to extinguish interior wildfires and restrict prescribed burning to upland areas and wet seasons are not necessarily advantageous to the swamp ecosystem.

The frequency of wildfires has apparently increased during the past 15 years to levels higher than during the past century, yet they are much smaller in size. Fire

detection and suppression techniques have improved during this period, so that more small fires are detected, and fires can be controlled while they are small. However, there has also been an increase in forest fuel loads in the swamp during the past 20 years, approaching pre-logging levels. The efficient fire control is presently restricting fire size, but may also permit accumulation of fuels that will carry an extensive, severe, uncontrollable fire with an ignition during an extreme drought period. The apparent cycle of approximately 30-50 years for extensive fires accompanying droughts may actually only be for fires that reduce the surface fuels slightly but do not burn into the peat, or decrease the possibility of another more severe fire from occurring with appropriate conditions. This is evident from the multiple "sweeps" of the 1931-1932 and 1954-1955 fires that burned repeatedly over the same areas. Although both of these fires occurred when water levels were low, the resulting vegetation changes were temporary. Vegetation was not killed in most areas, although localized mortality did occur (Hamilton 1984, 1982, Cypert 1973, 1961). Peat fires burned but were not extensive, and the accumulated litter provided fuels for many extensive fires (Hamilton 1984, 1982, Cypert 1973, 1961). The types of community-altering burns of past centuries evident in peat cores collected by Cohen et al. (1984) were scarce in these fires. This may mean that there are superimposed cycles of extensive fires accompanying drought every 30-50 years that remove a portion of the fuel but do not alter the landscape structure appreciably, and severe, extensive fires that occur every few hundred years with more severe drought periods, when fuel levels have accumulated in much greater amounts and the peat also burns. This cycling agrees with the periodicity proposed by Yin (1993)

based on size and frequency analysis (without regard to fire locations) of fires in Okefenokee Swamp during 1938-1989, and with periodicity of fires proposed by Rykiel (1984) based on nutrient and mineral cycling in the swamp. Formation of prairies or lakes in shrub and forested areas might then result from these severe, infrequent fires (Figure 5-18).

Logging that occurred in the swamp during 1890-1942 left various scars on the landscape. Since logging occurred there have been several fires in and around where logging occurred, probably consuming logging debris. Prior to logging most of these areas were cypress or pine dominated; 25% of the standing fuel in the swamp before logging was in tramline areas. By 1952, the logged areas had changed to dominance by shrub species, and accounted for 4.5% of the fuel load. By 1990 wet forest species dominated the tramlines and comprised 13.5% of the standing fuel load. As noted in Chapter 4, some of the logged areas have returned to a composition probably similar to that before logging. This was possible where coppice growth occurred, or where water-dispersed seeds were available. However, most of the area from which cypress was removed is dominated today by bay and blackgum communities, and cypress is less prominent, although in many cases still present. This is not an artifact of data scale; similar proportions in the landscape composition exist regardless of the data resolution. This alteration in species composition has the potential to affect many aspects of swamp ecology, such as hydrologic regimes by modifying evapotranspiration and flow rates, wildlife use of these areas, and fire occurrence and behavior. Cypress, bays, and blackgum tolerate wildfire to various degrees. They also carry fire differently (Ewel and

Return Frequency	Wildfire Extent, Severity	Drought Extent, Severity	Wildfire Control	Extent and Permanency of Effect to Vegetation
Century +	Regional; extensive and complete peat burn	Severe, > 1 year duration; extensive dry peat below exposed surface; deep peat saturated (> 1 m below surface)	Annual return to "normal" precipitation	Complete local to regional extent; decade(s) to semi-century duration
Semi-Century	Regional; extensive but patchy peat burn	Severe, > 1 year duration; patchy dry peat below exposed surface; deep peat saturated (> 1 m below surface)	Seasonal return to "normal" precipitation	Scattered local to regional extent; decade(s) duration
Decade	Local; minimal peat burn	Moderate, seasonal duration; moist peat below exposed surface (within 0.5 m)	Weather front/ storm precipitation	Minimal, local extent; seasonal duration
Seasonal	Local; minimal peat burn	Moderate, month duration; saturated peat surface	Suppression activities	Minimal to none, local extent; seasonal duration

Figure 5-18. Hypothesized return frequency, duration, extent, and intensity of drought and wildfires in Okefenokee Swamp, and the extent and permanency of subsequent vegetation changes.

Mistch 1978), an indication of their dependence on fire in maintaining their presence in the landscape. The increase of these species and the potential for them to alter movement and behavior of fire in the landscape may affect the response to future wildfires, and therefore influence the resultant landscape composition and structure.

These changes appear to be occurring independent of the sill's effects on the system. The hydrology model and water level recorder data analyses indicate that the sill's primary effects are during high water periods, by extending the hydroperiod and increasing inundation depths over roughly 15% of the refuge (see Chapter 3). The increase in hydroperiod and water depth depends on the location within this impact area. Areas further away are not flooded with as much water, and when water depths are high, theses distant areas are flooded at elevated depths for shorter periods than in areas closer to the sill. However the extended hydroperiod effects on species distributions are probably only occurring within the region bordered by the sill, south Floyd's Prairie, and midway to Craven's Hammock. This area has experienced flooding durations 1-4 times longer than they would be without the sill; water depths 0.30-1.00 m above pre-sill levels (see Chapter 3); and, species composition has changed since the sill was built (see Chapter 4). The Cypress Creek watershed has also been affected by the sill; drainage in this area may be accelerated during high water levels as the sill impounds water and reverses the hydraulic head at the river-creek junction. During average water conditions, water levels are higher in the sill's presence than in its absence. The mechanism for this change is unclear. Water levels in the Sweetwater Creek drainage, which is closer to the sill, should experience a much smaller change with sill removal than the Cypress Creek

area (Table 3-6). However, at extreme high water levels Sweetwater Creek also increases drainage as the hydraulic head reverses (Figure 3-19), as experienced in Cypress Creek. Manipulations in the perimeter landscape may also be responsible for increasing water levels in the Cypress Creek and Sweetwater basins, by direct contribution to the swamp where ditching and clear-cutting have occurred, or by increasing water levels between the swamp and the Suwannee River, and therefore slowing drainage of the swamp. Beyond these areas there are no substantial effects of the sill on water depths or hydroperiods that could be detected with the hydrology model. During low water periods, the sill impounds water only in the river and creek beds, and to some degree in the floodplain between Billy's Lake and the sill. It is during the low water and drought periods that wildfires have been most frequent in this area before and with the sill in place. Most of these fires occurred in the swamp interior and were lightning-caused. Two recorded fires during the last 30 years near the sill-affected area were incendiary and occurred during average water level periods in upland areas bordering the swamp; both were extinguished before they entered the swamp interior. Fires in the Cypress Creek watershed have occurred throughout the year; most of these were not ignited by lightning but were accidental, arson, or escaped prescribed fires. However, all of these fires occurred during low or drought conditions and were extinguished by fire suppression efforts or precipitation, not by water impounded by the sill. Thus the sill does not seem to be arresting the spread or occurrence of wildfires, as demonstrated by their continued occurrence since its construction in areas that burned by wildfires prior to the sill's construction.

The management plan of the Okefenokee Swamp ecosystem must consider the influences and expressions of past made-made perturbations on the current swamp landscape. Because these effects have modified species composition and community responses to disturbances, they must be considered when examining the current swamp landscape. At a minimum, the variability in vegetation distributions caused by fire and drought disturbances must be permitted to occur. The Okefenokee Swamp landscape evolved with this variability and will only be maintained with its continued influence.

CHAPTER 6
RELATIONSHIPS OF OKEFENOKEE SWAMP VEGETATION DISTRIBUTIONS AND THE HYDROLOGIC ENVIRONMENT

Introduction

The recognized position of wetlands between terrestrial and aquatic environments reflects a gradient of hydrologic conditions that requires the inhabitants endure a variety of physiological stresses (Mendelssohn and Burdick 1988). Occurrence and composition of specific types of wetlands are predominantly determined by the hydrologic environment (Mitsch and Gosselink 1986). The wetland's hydrologic regime (including flooding duration, depth, and periodicity) influences species composition by affecting nutrient transport and availability, substrate elevation, and substrate organic and inorganic composition (Flebbe 1973, Gosselink and Turner 1978, Rykiel 1977). Species' tolerances of these conditions, and competitive interactions for available resources while enduring these conditions, result in the standing vegetation composition, structure, and distribution (van der Valk and Welling 1988). Franz and Bazzaz (1977) suggested that life history processes such as timing and means of seed dispersal, germination requirements, and seedling growth rates, may be as important if not more important than physiological and structural mechanisms of flood tolerance in establishing vegetation and succeeding in competitive interactions along a flood gradient. Although average water

depth might affect species distributions to some degree (Gill 1970, Monk 1966), inundation duration and periodicity are the hydrologic signatures of most wetland types (Mitsch and Gosselink 1986, Penfound 1952). Deuver (1988) hypothesized that duration of inundation was more important than inundation depth in delineating species groups in Corkscrew Swamp, Florida. He also found that major community types clustered by maximum wet season water depths and hydroperiods. David (1996), Richardson et al. (1995), Gunderson (1994), Wood and Tanner (1990), and Loveless (1959) related species' occurrences to inundation depth, duration, and frequency in the Florida Everglades system. Harms et al. (1980) recorded differential mortality among species and sizes of trees flooded at different depths when Lake Ocklawaha was created with impoundment of the Ocklawaha River, Florida. Lowe (1986) also related vegetation patterns to the hydrologic regime of a Florida lake, although he attributed most of the lake margin zonation to fire history. Robel (1962) reported changes in growth forms of sago pondweed (*Potomogeton pectinatus*) in response to altered hydrologic regime. Changes in pond cypress basal structure with flooding duration are described by Kurz and DeMaree (1934). Wetland vegetation zonation is also a response to water sources and the effects of physical hydrologic processes on the substrate (Bornette and Amoros 1991). As indicated by these studies, even subtle alterations to a wetland's hydrologic features may result in changes in the species composition, structural forms, and hence the wetland type.

In an area undergoing succession, species occurrences are affected by light availability, substrate condition, proximity to seed or propagule source, and in a wetland,

the hydrologic regime. All of these factors are affected by the age and history of the site undergoing succession. Additional limitations as an area is colonized include a species' ability to use and sequester nutrients, compete for pollinators, and defend against herbivores. Species' plasticity to environmental change due to fires, freezes, wind, or flooding drives secondary succession; whether a community redevelops depends on the type and intensity of disturbance and the species's ability to grow and reproduce in spite of the altered conditions. Theoretically, any system that has reached a "climax state" is stable temporally and spatially only in a relative sense; succession is a cyclic process that occurs across the landscape at varying rates, creating a "moving mosaic" in response to disturbance events (White 1979). In a wetland the suite of species that can respond to the disturbance, perpetuating the succession cycle, is narrowed due to the physiological constraints of flooding. However, disturbance processes are part of the general phenomena of dynamics in the wetland community structure, and preservation of species in the landscape is dependent on preservation of the natural disturbance processes (White 1979).

The Suwannee River sill extended hydroperiods, decreased water depth variability, and increased water depths in approximately 18% of the Okefenokee Swamp (Chapter 3). Although alteration of the fire regime was intended with this structure, its greatest impact has been to extend high water depths during seasons less prone to wildfire occurrence (see Chapters 3 and 5). In 1990 the impounded region contained upland and wetland vegetation. Upland species were confined to the sand-based islands elevated above the river floodplain, however, and probably were not directly affected by

sill-induced changes to the surrounding environment, although the surrounding impounded conditions may have arrested fire movements off these islands (see Chapter 5). Floodplain forests of pond cypress (*Taxodium ascendens*), blackgum (*Nyssa sylvatica* v. *biflora*), dahoon holly (*Ilex cassine*), loblolly bay (*Gordonia lasianthus*), sweetbay (*Magnolia virginiana*), and Carolina ash *(Fraxinus caroliniana*), areas of shrub and shrub-forest mix, and deep and shallow water prairies also occurred in the area that experienced increased flooding depth and duration, and decreased flooding variation. Previous studies by Glasser (1986, 1985), Best et al. (1984), Hamilton (1984, 1982), Deuver and Riopelle (1984a, 1984b, 1983), and Cypert (1973, 1972, 1961) examined responses of species in the swamp to fire and logging, and Trowell (1987) hypothesized that periodic freezes kill swamp vegetation which may later affect fire behavior. However, examination of the role hydrology plays in shaping the compositions and distributions of swamp vegetation communities has been limited (Deuver 1982, 1979). In order to predict changes in swamp vegetation that might occur as a result of sill manipulation, the hydrologic environment of current swamp vegetation species needed better description. This chapter discusses the following issues:

1) What were the hydrologic environments during 1962-1995 at sites occupied by selected species during 1993-1994?

2) Using these species-environment descriptions, what changes in species distributions may occur in response to alterations of the swamp hydrologic environment by manipulations of the Suwannee River sill?

Methods

Vegetation Sampling

During 1993 and 1994 vegetation was sampled in 5 regions of the swamp (Figure 6-1). These areas were selected on the basis of accessibility and distance from the Suwannee River sill; as determined during initial reconnaissance, they included vegetation community types found throughout the swamp. Four of the regions were designated as prairies on 1964 USGS 1:24,000 topographic quadrangle maps (Chesser, Durdin, Floyd's, Sapling). The area bordered by the Suwannee River sill, Craven's Hammock, Billy's Lake, and the Pocket was designated the fifth sampling region (Sill Area).

Each region was subdivided into 4 sections (Northwest, Northeast, Southeast, Southwest); within each of these, 4 transects of various lengths (30-120 m) were randomly located, traversing the topographic gradient nearest to the randomly located starting point and marked with PVC poles pushed into the surface peat (Figure 6-2). Many transects crossed peat-based island perimeters if that was the topographic gradient closest to the initial random location of the transect starting point. Other gradients crossed prairie perimeters or traversed the general topographic rise across the landscape. Structural diversity in the vegetation was apparent along the transect gradient and was used to delineate zones (or coenoclines) for sampling species composition associated with topographic and hydrologic gradients (Elton and Miller 1954). Descriptions of

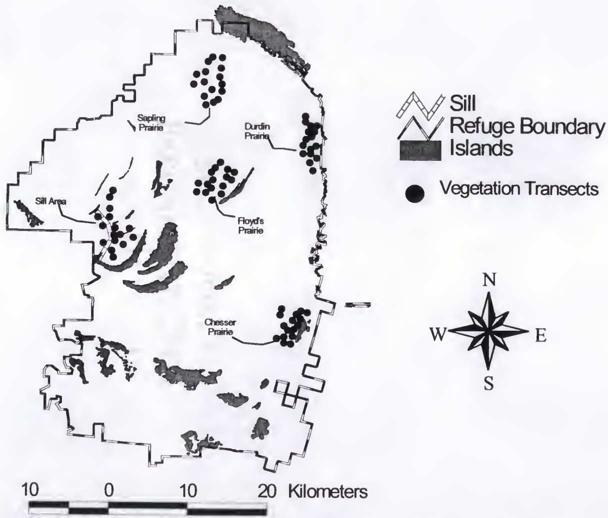


Figure 6-1. Locations of vegetation transects sampled during 1993-1994 in Okefenokee Swamp.

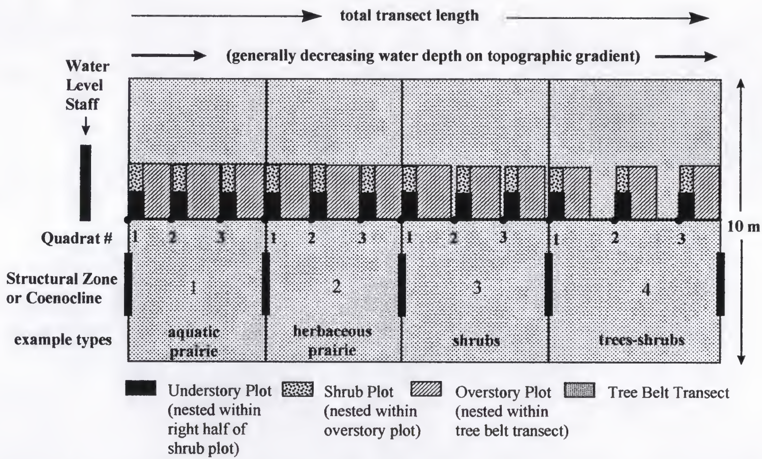


Figure 6-2. Schematic diagram of the placement of understory, overstory, and shrub plots, and tree belts along a vegetation transect sampled during 1993-1994 in Okefenokee Swamp.

structural types recognized in the Okefenokee Swamp as vegetation zones are reported in Table 6-1. All transects ran from the deep to the shallow end of the water depth gradient. Along the transect PVC poles marked the transitions between the vegetation zones, indicated by vegetation structural changes or coenoclines. Each zone was further subdivided into 2-4 equal-length segments and marked with PVC poles. These sites provided replicate samples within the zones, and the transects provide sample replication within the area (Figure 6-2).

During June-July 1993 and 1994 vegetation was sampled along all transects. Overstory data were collected in 1993, and understory sampling was conducted in 1994. For understory samples, a quadrat frame (0.5 m x 1.0 m) was placed with the lower right corner at the PVC site marker within each zone, and the short axis parallel to the transect gradient (Figure 6-2). Species percent cover was estimated in 5% increments at 3 heights ($\leq$ 0.3 m, 1.0 m, >1.0 m) above the ground surface; trace amounts were recorded as 1% cover. Cover totaled 100% at each height, and included estimates of open water, periphyton, and bare peat where appropriate. At the center of each quadrat, estimates of available photosynthetically active light (PAR, 0-199 μmol $s^{-1}m^{-2}$) at 0.3 m and 1.0 m were made with a Licor quantum sensor (LICOR, Inc., P.O. Box 4425, Lincoln, NE 68504); a measurement was also made near the transect origin where no canopy cover occurred at the start and end of light sampling and used to standardize measurements to the total available light during the sampling effort. Light measurements were made only on cloud-free days. Measurements were also adjusted for daily variations in sun-horizon position (AstroInfo, TUMASOFTware, Inc., Zephyr Services, 1900 Murray Avenue,

Table 6-1. Structural zone types recognized along sampled topographic/hydrologic gradients in Okefenokee Swamp.

Structural Zone Type	Abbreviation	Description
aquatic prairie	aqupra	deep water, floating vegetation with scattered herbaceous emergents, no overstory
aquatic-herbaceous prairie	aquher	deep water, floating-emergent herbaceous vegetation mix with floating dominant, no overstory
herbaceous prairie	herpra	moderate to shallow water, emergent herbaceous vegetation, no overstory
aquatic prairie-trees	aqutre	deep water, floating and emergent herbaceous vegetation, moderately dense tree overstory
aquatic prairie-shrubs	aqushr	deep water, floating and emergent herbaceous vegetation, moderately dense shrub overstory
herbaceous prairie-trees	hertre	shallow water, emergent herbaceous vegetation, moderately dense tree overstory
herbaceous prairie-trees-shrubs	hertsh	shallow water, emergent herbaceous vegetation, moderately dense tree and shrub mix overstory
shrubs-herbaceous prairie	shrher	shallow water, emergent herbaceous vegetation, dense shrub overstory
shrubs	shrubs	shallow to deep water, sparse herbaceous understory, dense shrub overstory
shrubs-trees	shrtre	shallow to deep water, sparse herbaceous understory, dense shrubs with scattered trees in overstory
trees-shrubs	treshr	shallow to deep water, sparse herbaceous understory, dense trees in overstory with scattered shrubs
trees	trees	shallow to deep water, sparse herbaceous understory, dense tree overstory

Pittsburgh, PA, 15217). A spherical densiometer (Forest Densiometers, 5733 Cornell Dr., Bartllesville, OK 74006) held at 1.5m above the peat surface was also used at each sample site to estimate overstory canopy cover. Water depths to the nearest 0.5 cm were recorded at the lower left, center, and upper right quadrat points; water depth at a staff installed at the transect origin was concurrently recorded. These staffs were calibrated to nearby (within 1000m) water level recorders by periodically measuring depths over time (every 3-4 months during 1992-1995) and noting changes in water surface elevation at the transects and recorders (see topographic survey discussion in Chapter 2); daily water surface elevations at the recorders could therefore be used to estimate daily water depths at sample sites along the transects when site water depths were not actually measured.

All transects sampled for understory in 1994 were sampled for overstory composition in 1993. A 2 m x 2 m quadrat sharing a common lower right corner with the understory quadrat was measured at each overstory site (Figure 6-2). Percent cover of each woody overstory species estimated at 1 m, 2 m, and >2 m heights were recorded, and presence of stems <2.5 cm, 2.5-10.0 cm, and >10.0 cm dbh (diameter at breast height, 1.5 m above ground) within the quadrat was recorded by species. During 1994, transects randomly selected for seed bank composition analysis (see Chapter 7) were also sampled for additional shrub and tree composition. This information included a large number of most species along the transects, and provided estimates of species densities (number per m^2) along the transects. In each shrub sample quadrat along a transect, stems of each shrub species were counted within a 0.5 m x 2 m quadrat placed with the site marker at the lower right corner, and the quadrat's short side parallel to the transect

gradient (Figure 6-2). Several quadrat sizes and orientations were initially sampled; this dimension and placement provided the highest densities and species richness for the area sampled. A belt extending the transect's length and 5 m out from either side and 2 m beyond the last sample site, was used to describe the transect's tree composition (Figure 6-2). All trees >1.0 m tall within the belt were identified, counted, and a dbh measurement recorded; shrub species were not recorded in this sample. Water depths were estimated for the shrub quadrats using relationships established for the understory samples; water depths for the understory quadrats were assumed representative of those in the 0.5 m x 2.0 m shrub quadrats. Estimates of the water depths for the trees recorded along the belt transects were made by structural zone; water depths measured at the understory quadrats were averaged across the zone, and this value represented the water depth for species encountered in the zone. Long-term water level data for structural zones in the belt transects were estimated from recorder data as with understory quadrats.

Preparation of Hydrologic Data

Although water depth may limit distributions of some species, duration of inundation and variability in water levels may also affect species' occurrences. Daily water level data recorded and estimated at sites in the areas of the vegetation transect sampling were available for 1941-1995 (see chapter 2). These data were used in assessment of the hydrology model discussed in Chapter 3. Extension of these data to the vegetation transects for calculation of water depths, water depth variability, and flooding duration at each site during 1941-1995 were made based on the elevation

relationships among sampled sites, staffs in place at each transect, and the nearest (within 1000m) water level recorders. These transect-recorder pairs are listed in Table 6-2. Daily water depths estimated for each transect site were summarized in LOTUS 123 spreadsheets into several variables. Average daily water depth during sill gate closure (1962-June 1995) was calculated at each site; depths during this interval were not different statistically from those summarized by decades during the same period (Table 2-20). Average water depths at each sampled site were also calculated for growing (March-October) and non-growing (November-February) seasons during 1962-June 1995.

Duration of inundation with sill gate closure (1962-June 1995) was also calculated for each quadrat and for several inundation depths (depth classes, denoted DC in figures and tables), providing an indication of whether a species was found where peat was usually inundated, and also a description of the inundation depth. Inundation depth classes were defined by relationships of general plant height to water depth (Table 6-3). Reliability of water depths measured below the peat surface were uncertain, so minimum estimated depths were summarized as ≤ 0 m. This indicated soils that were dry, moist, or possibly saturated, but the surface was not inundated. Water depths > 0 m and ≤ 0.30 m ("shallow" water depth) indicated submergence of at least the bases of herbs and shrubs, but not necessarily trees. Depths > 0.30 m ("deep" water depth) indicated submergence of most tree bases. These depths were further subdivided to examine differences in peaks of species occurrence and average daily water depths. Estimated water depths >0.00 m-0.05 m represented peat that was inundated, but plants were generally not submerged. Smaller stature herbs were submerged by water depths 0.05 m-0.15 m;

Table 6-2. Recorders and nearest survey benchmarks used to estimate water surface elevations at vegetation transects during 1960-1995.

Area	Recorder	Survey Benchmark[a]	Transect[b]
Chesser Prairie	Seagrove Lake	17	8,9,14
	Seagrove lake	18	10, 15
	Chesser Prairie	1	1, 3, 4, 7, 12, 13
	Chesser Prairie	2	2, 5, 6, 11, 16
Durdin Prairie	Kingfisher Landing	31	18
	Durdin Prairie	32	17, 19, 22, 23, 25
	Durdin Prairie	33	20, 21, 24, 26, 29
	Durdin Prairie	34	27
	Durdin Prairie	54	28, 30, 31, 32
Sapling Prairie	Sapling Prairie	22	74, 75, 76, 77
	Sapling Prairie	23	64, 65, 66
	Sapling Prairie	24	69, 70, 71, 72, 73
	Sapling Prairie	25	67, 68
	Sapling Prairie	53	78, 79
Floyd's Prairie	Floyd's Prairie	44	34, 46, 47
	Floyd's Prairie	45	37, 42, 43, 45
	Floyd's Prairie	46	38, 39
	Floyd's Prairie	47	41, 48
	Floyd's Prairie	48	33, 35, 36, 40, 44
Sill Area	Suwannee River	57	49, 80
	Suwannee River	58	50, 63
	Suwannee River	59	58
	Suwannee River	63	51, 53, 54, 60

Area	Recorder	Survey Benchmark[a]	Transect[b]
	Sill (Brown Trail)	60	57
	Sill (Brown Trail)	61	56
	Sill (Brown Trail)	64	52, 55, 59, 61, 62

[a] Survey benchmarks were within 1000m of transect locations.
[b] Transect locations are listed in Appendix C.

Table 6-3. Inundation depth classes defined for analysis of species occurrence in hydrologic environments.

Depth Class (DC)	General Inundation Description	Water Depth Range (m)	Extent of Plant Submergence
DC1	no inundation	depth $\leq$ 0.00	no inundation
DC2	shallow	0.00 < depth $\leq$ 0.05	inundated peat; small plants not submerged
DC3	shallow	0.05 < depth $\leq$ 0.15	small herbs submerged
DC4	shallow	0.15 < depth $\leq$ 0.30	large herbs and bases of shrubs submerged
DC5	deep	0.30 < depth $\leq$ 0.60	tree bases submerged
DC6	deep	0.60 < depth $\leq$ 1.00	tree bases submerged; common in sill area
DC7	deep	depth > 1.00	tree bases submerged; common in sill area

larger herbs and the bases of most shrubs were submerged at water depths 0.15 m-0.30 m. Tree bases were generally submerged when water depths exceeded 0.30 m. Further subdivisions of 0.60 m-1.0 m and >1.0 m permitted examination of species occurrences in extreme water depths common in the sill-affected area (Table 6-3). The number and proportion of days during 1962-June 1995 that a quadrat was in each of these 7 water depth categories was totaled. Percentages were combined to calculate proportions for combined depth classes, particularly depth ≤ 0 m (no inundation), $0 <$ depth ≤ 0.30 m (shallow inundation), and depth > 0.30 m (deep inundation).

Analysis of Vegetation Data

Percent cover estimates provided information about species occurrence from two perspectives. At the landscape level, environments of sampled quadrats represented the suite of hydrologic conditions available throughout the swamp, regardless of species occurrence. Species percent cover estimates for these samples were logit-transformed ($y=ln[p/1-p]$, where p = species percent cover) to normalize skewed distributions due infrequent species occurrence. Site descriptions where species were present represent the environment on a smaller, local scale, without consideration of the swamp-wide environment (which includes areas where species were absent). Therefore, datasets were re-sampled to include only quadrats where species occurred, so that species-environment relationships could be examined.

Comparisons of conditions where species occurred with conditions where species were absent suggested local and landscape-level differences in hydrologic environments.

Examination of occupied sites refined the site descriptions beyond features that determined species presence or absence, to indicate conditions most favorable to species' abundances. *t*-test (average water depth) and Wilcoxon rank-sum (percent of interval in each depth class) procedures were used to identify differences in species abundance among hydrologic conditions.

Statistically significant relationships among species occurrences and environmental variables were identified using a mixture experiment format. In mixture experiments, frequently used in agricultural research to analyze suitability of component blends (such as proportions of juices in fruit juice blends), the measured characteristic (e.g., juice preference) is assumed to be dependent on the relative proportions in each of the mixture ingredients (Cornell and Harrison 1997). Location of a point (the juice blend "suitability score") in factor space can be described by a multiple regression model. The *n*-dimensional model can be visualized in an *n*-dimensional plot or surface, to illustrate interaction affects among components and significance of components in affecting the measured characteristic (suitability score) that are identified in development of the best regression model. These surfaces (models) can be statistically compared with F-tests to determine similarities of measured characteristics among different mixtures.

For analysis of plant species association with hydrologic environments, the species abundance (representing the suitability of the hydrologic environment of a sampled quadrat), could be described by the proportion of time a site spent in each water depth condition (no inundation, shallow, deep), interactions of time spent at these depths, and the covariate effects of light availability and transect. The general model form

(Cornell and Harrison 1997) of the 3-dimensional model is:

$$\text{response} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{12} x_1 x_2 + \beta_{13} x_1 x_3 + \beta_{23} x_2 x_3 + \{\beta_{123}\, x_1 x_2 x_3\} + \epsilon$$

where response is the species' abundance, β's are estimated values describing the relationships among the components (species occurrence and hydrologic conditions) in the experimental data, and x_n represents the duration of flooding in each depth. The 3-dimensional model was chosen because the hydrologic environment could be described by 3 proportions describing the duration and of inundation and totaling 100% of the sample interval (% time with no inundation+% time with shallow inundation+% time with deep inundation=100% time). The term $\{\beta_{123}\, x_1 x_2 x_3\}$ was replaced in this analysis with the covariates (light availability and transect) and their interactions. The 3-dimensional models were developed and significance of parameters assessed using the SAS version 6.12 *Proc GLM* procedure (SAS Institute, Inc., Cary, NC 27513). Model reduction was based on Mallow's C_p (Myers 1990) and effects of forward and backward addition of components to changes in Type III sums of squares. Models were similarly assessed for entire data sets (all sampled quadrats) and reduced data sets (quadrats only where species present).

Species models that indicated a significant relationship between the species abundance and no inundation to shallow inundation conditions (0-0.30 m water depth) were modeled again to determine if abundance differed among inundation depths of 0-0.05 m, 0.05-0.15 m, and 0.15-0.30 m. The models were developed and significance of

parameters assessed using the SAS *Proc GLM* procedure as discussed above. Models were similarly assessed for entire data sets (all quadrat data regardless of species presence) and reduced data sets (quadrat data only where species were present).

In addition to species richness, Shannon-Weiner diversity indices (Kent and Coker 1992) were calculated for all understory, shrub, and tree plots to assess differences in species diversities among hydrologic environments and sample regions (Chesser Prairie, Durdin Prairie, Floyd's Prairie, Sapling Prairie, sill area). Diversity measures were modeled as described above.

Observed and model-predicted density or cover estimates were diagramed in 3-dimensional plots to visualize the shape of the modeled relationships (Figure 6-3). Similarities among species occurrences and hydrologic conditions were more easily visualized when illustrated in this manner; species could be grouped based on common plot shape, representing species with similar relationships between abundance and the modeled hydrologic parameters. Plots were constructed with SigmaPlot software (version 2.01, Jandel Corporation, San Rafael, CA 94912) using observed and model-predicted abundances calculated with SAS-Proc GLM procedures described above, and blindly (without knowledge of plot species identification) clustered by common plot shapes to determine if species' groups or associations might exist.

Changes in the swamp hydrologic environment predicted from with-sill and without-sill hydrology models (Table 3-6) were compared with diagramed and modeled species-environment relationships to ascertain vegetation changes that might occur with

GRAPH 1

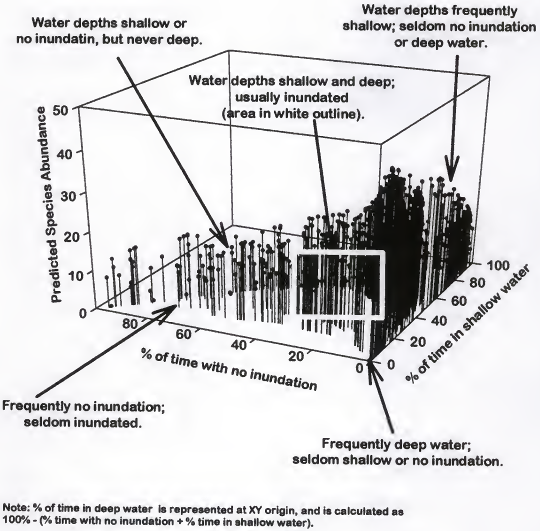
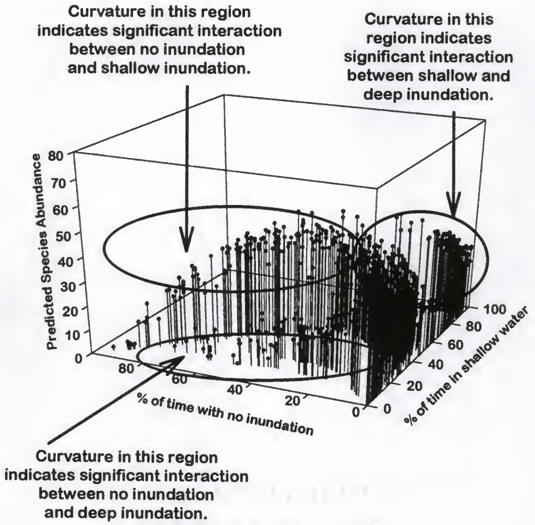


Figure 6-3. Example interpretation of axes (Graph 1) and curvatures (Graph 2) on 3-dimensional plots of model-predicted abundances of species with flooding depth and duration.

GRAPH 2



Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-3--continued.

sill removal. Changes in hydrologic environments that could lead to species changes were summarized by swamp region.

Results

Species' Environments

Most species occurred at similar average daily water depths (Figure 6-4). Figure 6-5 illustrates the gradients from deep to shallow and constant to variable water depths occurring along the sampled transects. Figure 6-6 indicates substantial overlap in species' abundances (for a composite of all samples) across the exposure duration gradient; however, differences among species and species groups emerge when the duration and degree of inundation are isolated. Descriptors of the percent of time spent in each depth class are listed in Table 6-4 for 49 species occurring in at least 3 of the 944 understory plots, 489 shrub plots, or 166 tree belt samples. Hydrologic conditions where species were absent are listed in Table 6-5. These comparisons indicate that most of the sampled species occur under specific conditions of light availability, hydroperiod, and inundation depth in the swamp. Frequency quartiles of flooding durations in each water depth range, for locations where species abundances were greatest (90-100% of the maximum cover or density), are described in Figure 6-7. For each water depth range or depth class, the most frequent (mode) duration of inundation, the maximum flooding duration (range) where the species occurred, and the maximum flooding duration (range) of all sampled quadrats are also indicated. These summaries suggested that species

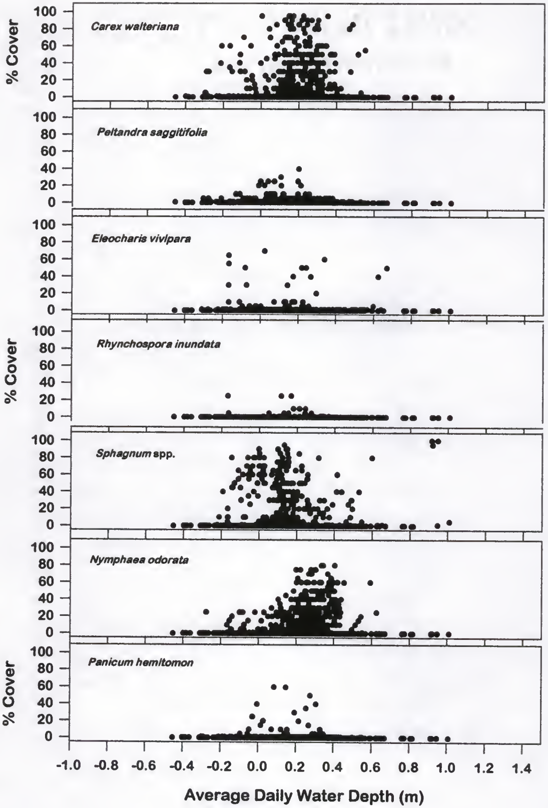


Figure 6-4. Average daily water depths (1962-1995) for species recorded at Okefenokee Swamp sample sites during 1993-1994.

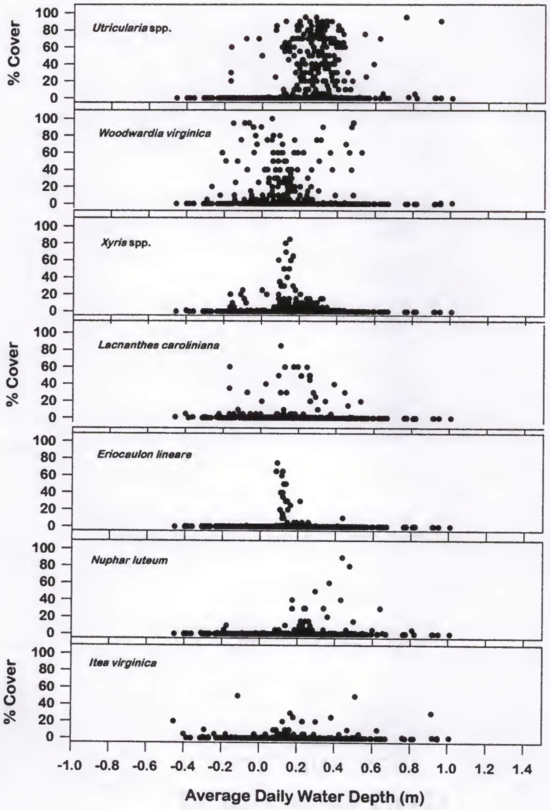


Figure 6-4--continued.

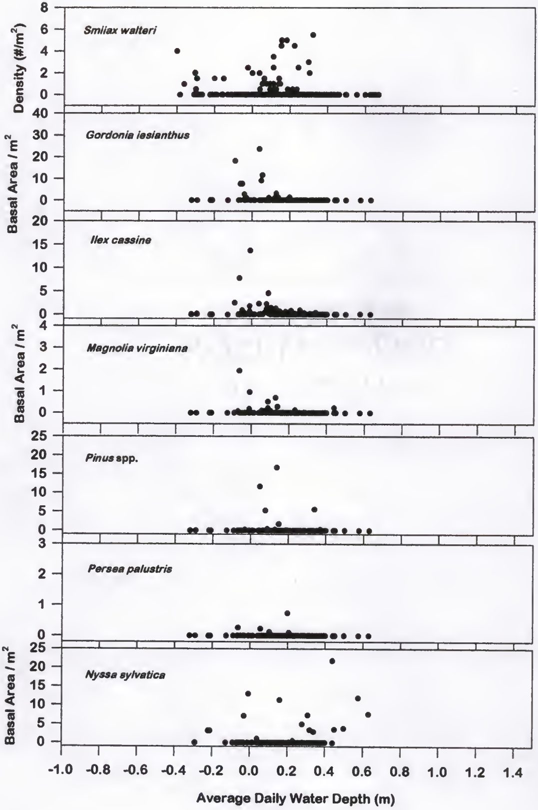


Figure 6-4--continued.

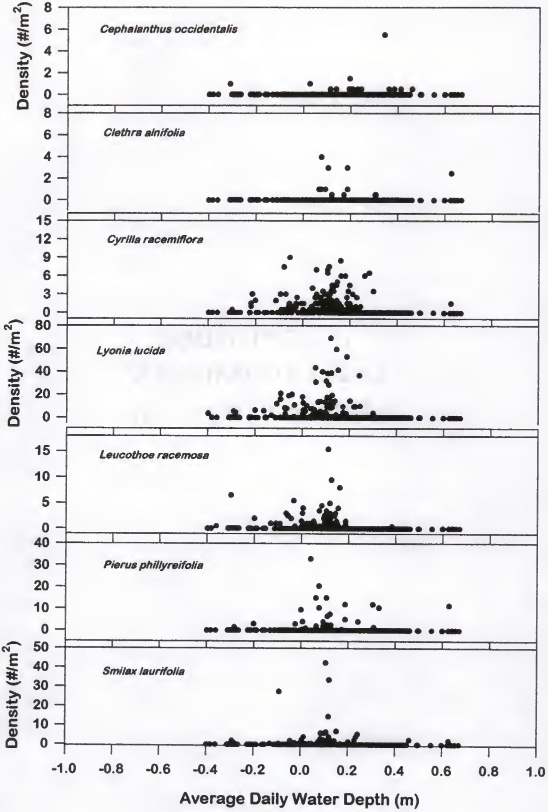


Figure 6-4--continued.

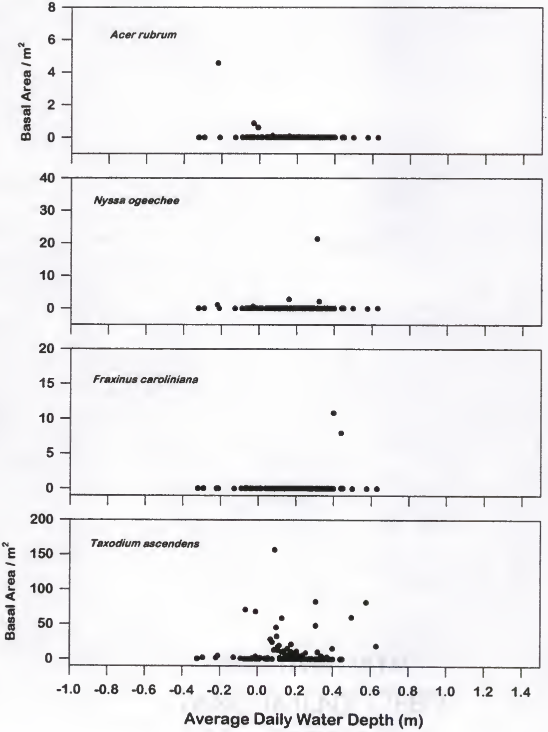


Figure 6-4--continued.

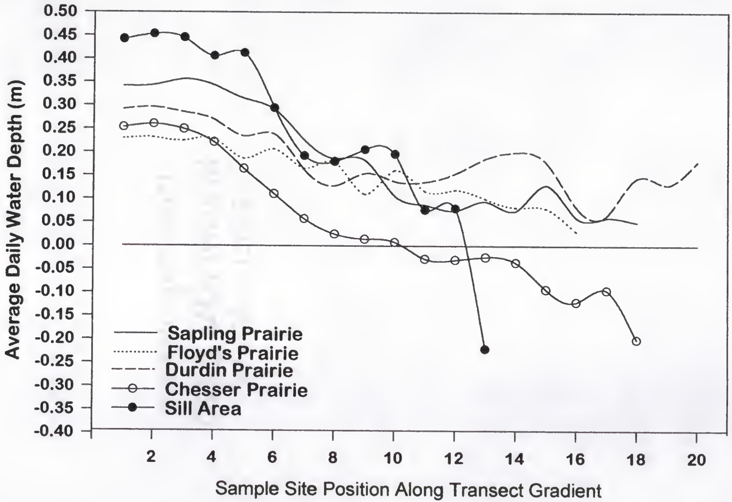


Figure 6-5. Average daily water depths along vegetation transects sampled in Okefenokee Swamp during 1993-1994.

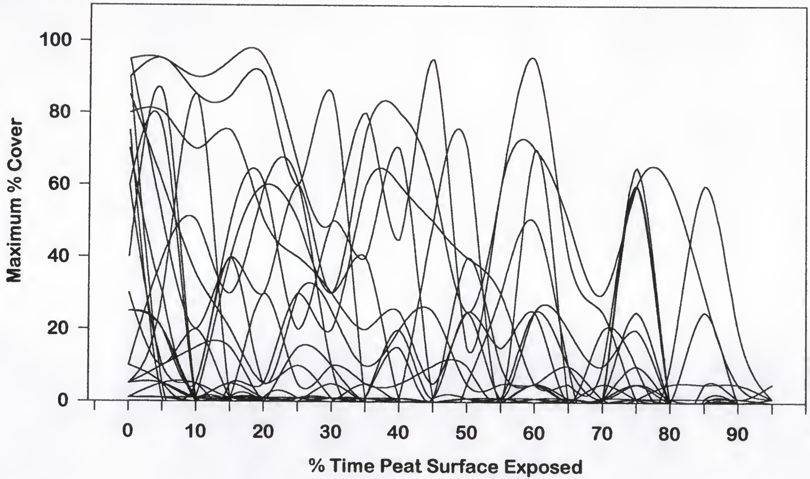


Figure 6-6. Trends in abundances of all species occurring along an exposure gradient during 1993-1994 in Okefenokee Swamp.

Table 6-4. Hydrologic environments during 1962-1995 of species occurring in vegetation sample plots during 1993-1994. Water depth conditions (DC) are described in the table footnote.

Parameter	*Carex walteriana*	*Nymphaea odorata*	*Xyris* spp.	*Utricularia* spp.
Sample Size	437	361	248	244
Water Depth $\bar{x} \pm$ SD (m)	0.17 ± 0.14	0.24 ± 0.13	0.17 ± 0.12	0.29 ± 0.14
Minimum Water Depth (m)	-0.40	-0.28	-0.40	-0.17
Maximum Water Depth (m)	0.55	0.62	0.44	0.95
$\bar{x}$ % Time in DC1 (SD) [a]	17.7 (20.8)	11.4 (16.0)	13.0 (18.9)	8.9 (12.2)
$\bar{x}$ % Time in DC2 (SD)	6.1 (4.3)	4.1 (3.7)	6.6 (5.4)	3.4 (2.9)
$\bar{x}$ % Time in DC3 (SD)	18.7 (12.5)	13.7 (12.2)	25.1 (16.9)	11.2 (9.5)
$\bar{x}$ % Time in DC4 (SD)	30.5 (14.2)	30.2 (15.7)	36.0 (18.6)	29.1 (14.4)
$\bar{x}$ % Time in DC5 (SD)	24.8 (20.2)	37.1 (24.2)	18.3 (20.3)	41.8 (21.6)
$\bar{x}$ % Time in DC6 (SD)	2.1 (3.9)	3.3 (6.3)	1.0 (1.8)	4.8 (7.7)
$\bar{x}$ % Time in DC7 (SD)	0.1 (0.8)	0.2 (1.1)	0.0 (0.1)	0.9 (5.0)
Mode of %Time in DC1	0	0	0	0
Mode of %Time in DC2	0	0	0	0
Mode of %Time in DC3	27.5	0	49.1	0
Mode of %Time in DC4	26.8	27	32.1	26.8
Mode of %Time in DC5	1.9	0.2	1.9	31.1
Mode of %Time in DC6	0	0	0	0
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	0, 95	0, 88.9	0, 95	0, 78.6
Minimum, Maximum % Time in DC2	0, 27.5	0, 24	0, 35.7	0, 17.1
Minimum, Maximum % Time in DC3	0, 65.1	0, 59.6	0, 64.4	0, 57.8
Minimum, Maximum % Time in DC4	1, 76.2	1.2, 79.9	0.8, 79.9	0.3, 74.4
Minimum, Maximum % Time in DC5	0, 96.8	0.1, 98.2	0, 98.2	0.1, 98.3
Minimum, Maximum % Time in DC6	0, 36.7	0, 53.1	0, 11.7	0, 53.1
Minimum, Maximum % Time in DC7	0, 12.0	0, 12.0	0, 0.5	0, 44.3
Overstory % Cover, $\bar{x} \pm$ SD	29.3 ± 36.8	13.2 ± 27.1	25.5 ± 35.1	20.8 ± 34.1
% Low Level Light Available, $\bar{x} \pm$ SD [b]	47.6 ± 35.0	68.6 ± 34.3	56.5 ± 35.5	60.3 ± 38.8
% High Level Light Available, $\bar{x} \pm$ SD [c]	68.5 ± 33.3	82.7 ± 25.6	71.0 ± 33.0	74.6 ± 30.7

Parameter	*Eriocaulon lineare*	*Rhynchospora inundata*	*Eleocharis baldwinii/ vivipara*	*Panicum hemitomon*
Sample Size	44	35	157	228
Water Depth $\bar{x} \pm$ SD (m)	0.2 ± 0.1	0.17 ± 0.13	0.16 ± 0.20	0.19 ± 0.15
Minimum Water Depth (m)	-0.10	-0.17	-0.31	-0.30
Maximum Water Depth (m)	0.40	0.37	0.67	0.55 .
$\bar{x}$ % Time in DC1 (SD) [a]	5.3 (9.0)	13.6 (21.8)	30.9 (21.5)	15.8 (20.0)
$\bar{x}$ % Time in DC2 (SD)	6.9 (4.7)	5.8 (7.2)	6.3 (5.0)	5.4 (4.8)
$\bar{x}$ % Time in DC3 (SD)	39.3 (19.7)	19.8(17.6)	16.5 (13.3)	18.1 (14.9)
$\bar{x}$ % Time in DC4 (SD)	38.5 (19.1)	36.4 (21.9)	19.8 (15.6)	29.9 (16.4)
$\bar{x}$ % Time in DC5 (SD)	9.9 (21.4)	24.1 (25.1)	13.8 (11.5)	27.5 (24.0)
$\bar{x}$ % Time in DC6 (SD)	0.0 (0.1)	0.2 (0.6)	7.1 (8.6)	2.8 (5.3)
$\bar{x}$ % Time in DC7 (SD)	0.0 (0.0)	0 (0)	5.5 (8.3)	0.5 (2.3)
Mode of %Time in DC1	6.7	0	0	0
Mode of %Time in DC2	10.1	0	2.8	0
Mode of %Time in DC3	49.1	0.2	5.5	0
Mode of %Time in DC4	32.1	28.7	12.3	28.7
Mode of %Time in DC5	1.9	0.1	12.3	0.8
Mode of %Time in DC6	0	0	0	0
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	0, 59.2	0, 78.6	0, 88.9	0, 90.4
Minimum, Maximum % Time in DC2	0, 17.3	0, 35.7	0, 36.5	0, 35.7
Minimum, Maximum % Time in DC3	0, 65.1	0, 59.6	0.4, 57.6	0, 59.6
Minimum, Maximum % Time in DC4	1.2, 76.8	1.6, 79.9	2.0, 76.4	1.2, 79.9
Minimum, Maximum % Time in DC5	0.1, 98.2	0, 89.6	0, 66.3	0, 98.2
Minimum, Maximum % Time in DC6	0, 0.5	0, 2.9	0, 29.1	0, 36.7
Minimum, Maximum % Time in DC7	0, 0	0, 0	0, 34.0	0, 18.2
Overstory % Cover, $\bar{x} \pm$ SD	10.9 ± 16.9	10.9 ± 17.5	21.4 ± 32.7	16.7 ± 28.5
% Low Level Light Available, $\bar{x} \pm$ SD [b]	66.0 ± 33.3	71.5 ± 30.1	49.4 ± 35.0	61.3 ± 34.9
% High Level Light Available, $\bar{x} \pm$ SD [c]	88.0 ± 18.1	87.4 ± 19.7	70.8 ± 29.4	79.7 ± 25.9

Parameter	*Lacnanthes caroliniana*	*Nuphar luteum*	*Woodwardia virginica*	*Peltandra virginica*
Sample Size	266	68	197	356
Water Depth $\bar{x} \pm$ SD (m)	0.10 ± 0.16	0.26 ± 0.21	0.12 ± 0.19	0.15 ± 0.14
Minimum Water Depth (m)	-0.45	-0.31	-0.29	-0.45
Maximum Water Depth (m)	0.53	0.81	1.76	0.53
$\bar{x}$ % Time in DC1 (SD) [a]	28.5 (25.4)	23.0 (19.8)	25.0 (24.2)	19.8 (22.1)
$\bar{x}$ % Time in DC2 (SD)	7.5 (4.7)	3.5 (2.9)	8.5 (5.5)	6.9 (4.7)
$\bar{x}$ % Time in DC3 (SD)	21.8 (15.0)	11.2 (11.8)	24.9 (15.8)	21.7 (14.4)
$\bar{x}$ % Time in DC4 (SD)	25.0 (16.2)	22.5 (22.8)	26.0 (15.6)	30.2 (15.0)
$\bar{x}$ % Time in DC5 (SD)	13.4 (15.4)	20.6 (18.8)	13.3 (17.9)	19.8 (19.1)
$\bar{x}$ % Time in DC6 (SD)	2.4 (5.2)	11.0 (9.0)	1.7 (4.7)	1.5 (3.3)
$\bar{x}$ % Time in DC7 (SD)	1.3 (4.5)	8.2 (9.5)	0.6 (6.5)	0 (0.1)
Mode of %Time in DC1	6.7	0	6.71	0
Mode of %Time in DC2	10.1	2.2	10.1	0
Mode of %Time in DC3	49.1	5.5	49.1	49.1
Mode of %Time in DC4	32.1	12.3	32.1	32.1
Mode of %Time in DC5	0.2	19.0	0	0.1
Mode of %Time in DC6	0	0	0	0
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	0, 96.6	0, 78.2	0, 96.8	0, 96.6
Minimum, Maximum % Time in DC2	0, 36.5	0, 13.1	0, 35.7	0, 35.7
Minimum, Maximum % Time in DC3	0.4, 65.1	0, 50.6	0, 65.1	0, 65.1
Minimum, Maximum % Time in DC4	0.5, 76.4	0.3, 76.8	0.1, 80.5	0.2, 79.9
Minimum, Maximum % Time in DC5	0, 66.3	1.2, 98.3	0, 98.2	0, 98.2
Minimum, Maximum % Time in DC6	0, 32.0	0, 29.1	0, 32.0	0, 32.0
Minimum, Maximum % Time in DC7	0, 26.9	0, 35.7	0, 90.5	0, 0.9
Overstory % Cover, $\bar{x} \pm$ SD	28.6 ± 35.6	9.6 ± 26.5	39.6 ± 38.1	32.8 ± 36.6
% Low Level Light Available, $\bar{x} \pm$SD [b]	45.7 ± 35.3	48.9 ± 35.8	33.2 ± 33.6	44.8 ± 35.5
% High Level Light Available, $\bar{x} \pm$SD [c]	69.0 ± 33.3	77.7 ± 21.1	59.4 ± 37.0	64.5 ± 35.0

Parameter	*Sphagnum* spp.	*Andropogon virginica*	*Dulichium arendinacium*	*Orontium aquaticum*
Sample Size	308	61	162	133
Water Depth $\bar{x} \pm$ SD (m)	0.18 ± 0.26	0.17 ± 0.06	0.18 ± 0.24	0.26 ± 0.12
Minimum Water Depth (m)	-0.22	-0.04	-0.21	-0.17
Maximum Water Depth (m)	1.76	0.35	1.66	0.62
$\bar{x}$ % Time in DC1 (SD) [a]	20.4 (21.9)	5.8 (5.8)	20.6 (20.3)	10.2 (12.9)
$\bar{x}$ % Time in DC2 (SD)	7.7 (5.7)	6.5 (4.1)	6.8 (4.1)	4.2 (4.6)
$\bar{x}$ % Time in DC3 (SD)	24.4 (16.8)	34.9 (16.4)	21.7 (13.7)	12.8 (12.2)
$\bar{x}$ % Time in DC4 (SD)	28.6 (18.9)	42.2 (16.6)	29.8 (17.2)	28.0 (14.1)
$\bar{x}$ % Time in DC5 (SD)	13.4 (17.4)	10.2 (14.0)	15.7 (14.9)	42.3 (25.5)
$\bar{x}$ % Time in DC6 (SD)	2.5 (6.2)	0.4 (1.0)	2.7 (5.7)	2.6 (5.6)
$\bar{x}$ % Time in DC7 (SD)	3.1 (13.1)	0 (0)	2.8 (12.7)	0.1 (0.2)
Mode of %Time in DC1	0	6.7	0	0
Mode of %Time in DC2	0	10.1	0	0
Mode of %Time in DC3	49.1	49.1	20.1	0
Mode of %Time in DC4	32.1	32.1	26.1	26.6
Mode of %Time in DC5	0.1	1.9	0.8	35.3
Mode of %Time in DC6	0	0	0	0
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	0, 88.1	0, 32.5	0, 82.3	0, 78.6
Minimum, Maximum % Time in DC2	0, 36.5	0, 18.7	0, 19.7	0, 35.7
Minimum, Maximum % Time in DC3	0, 65.1	1.2, 58.2	0.4, 56.2	0, 59.6
Minimum, Maximum % Time in DC4	0.6, 80.5	12.2, 76.8	0.7, 76.8	1.5, 79.9
Minimum, Maximum % Time in DC5	0, 98.2	0, 74.0	0, 61.3	0, 98
Minimum, Maximum % Time in DC6	0, 32.0	0, 4.3	0, 29.5	0, 53.1
Minimum, Maximum % Time in DC7	0, 90.5	0, 0.2	0, 88.2	0, 2.1
Overstory % Cover, $\bar{x} \pm$ SD	24.7 ± 34.0	8.2 ± 19.5	26.8 ± 35.7	12.0 ± 25.3
% Low Level Light Available, $\bar{x} \pm$SD [b]	49.8 ± 36.3	68.1 ± 28.7	49.6 ± 35.2	67.2 ± 37.3
% High Level Light Available, $\bar{x} \pm$SD [c]	71.8 ± 32.6	88.4 ± 18.0	72.1 ± 31.1	84.5 ± 25.5

Table 6-4--continued.

Parameter	*Saggetaria graminea*	*Triadenum virginicum*	*Sarracenia flava*	*Sarracenia psittacenia*
Sample Size	66	42	61	15
Water Depth $\bar{x} \pm$ SD (m)	0.15 ± 0.10	0.14 ± 0.08	0.13 ± 0.10	0.12 ± 0.05
Minimum Water Depth (m)	-0.17	-0.17	-0.17	-0.06
Maximum Water Depth (m)	0.35	0.29	0.41	0.16
$\bar{x}$ % Time in DC1 (SD)[a]	14.9 (18.8)	7.9 (16.4)	10.1 (18.1)	8.4 (13.5)
$\bar{x}$ % Time in DC2 (SD)	6.9 (4.6)	6.7 (4.5)	5.8 (0.5)	8.4 (3.1)
$\bar{x}$ % Time in DC3 (SD)	26.8 (16.2)	36.6 (17.0)	38.8 (18.9)	47.8 (9.9)
$\bar{x}$ % Time in DC4 (SD)	35.3 (16.9)	43.0 (20.2)	33.9 (18.1)	33.5 (9.7)
$\bar{x}$ % Time in DC5 (SD)	15.4 (16.1)	5.6 (7.7)	8.5 (19.4)	1.9 (1.4)
$\bar{x}$ % Time in DC6 (SD)	0.6 (1.0)	0.1 (0.6)	0 (0.2)	0 (0)
$\bar{x}$ % Time in DC7 (SD)	0 (0)	0 (0)	0 (0)	0 (0)
Mode of %Time in DC1	0	0.1	0	1.9
Mode of %Time in DC2	5.7	0.6	0	6.4
Mode of %Time in DC3	15.9	26.8	49.1	18.2
Mode of %Time in DC4	30.3	16.5	32.1	15.2
Mode of %Time in DC5	1.2	2.3	0.2	1.2
Mode of %Time in DC6	0	0	0	0
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	0, 78.6	0, 78.6	0, 76.6	1.9, 56.6
Minimum, Maximum % Time in DC2	0, 24.8	0.3, 17.1	0, 24.0	4.8, 17.1
Minimum, Maximum % Time in DC3	1.2, 57.6	5.5, 57.8	0, 65.1	18.2, 58.3
Minimum, Maximum % Time in DC4	2.5, 76.4	2.5, 76.8	2.8, 76.0	15.2, 49.5
Minimum, Maximum % Time in DC5	0, 74.0	0.1, 41.5	0.1, 96.8	0.4, 5.5
Minimum, Maximum % Time in DC6	0, 3.8	0, 3.5	0, 1.4	0, 0
Minimum, Maximum % Time in DC7	0, 0.1	0, 0	0, 0	0, 0
Overstory % Cover, $\bar{x} \pm$ SD	15.3 ± 26.5	3.7 ± 10.6	12.6 ± 16.7	14.3 ± 22.6
% Low Level Light Available, $\bar{x} \pm$SD[b]	62.0 ± 30.6	70.6 ± 27.3	54.6 ± 31.4	48.8 ± 27.5
% High Level Light Available, $\bar{x} \pm$SD[c]	80.8 ± 23.7	89.9 ± 17.1	80.5 ± 24.9	83.1 ± 28.1

Parameter	*Eleocharis robbinsii*	*Iris virginiana*	*Decodon verticillatus*	*Rhynchospora chalerocephala/ wrightiana*
Sample Size	91	43	26	44
Water Depth $\bar{x} \pm$ SD (m)	0.30 $\pm$ 0.07	0.18 $\pm$ 0.08	0.19 $\pm$ 0.14	0.10 $\pm$ 0.14
Minimum Water Depth (m)	0.10	-0.09	-0.11	-0.17
Maximum Water Depth (m)	0.62	0.33	0.50	0.40
$\bar{x}$ % Time in DC1 (SD)[a]	6.3 (4.5)	11.6 (10.8)	10.9 (16.5)	20.1 (27.8)
$\bar{x}$ % Time in DC2 (SD)	3.0 (1.6)	7.8 (5.2)	6.6 (7.6)	7.7 (5.7)
$\bar{x}$ % Time in DC3 (SD)	10.1 (4.4)	26.7 (14.2)	25.1 (18.7)	30.3 (18.7)
$\bar{x}$ % Time in DC4 (SD)	30.7 (7.2)	33.7 (12.2)	37.6 (23.6)	33.6 (23.0)
$\bar{x}$ % Time in DC5 (SD)	44.5 (9.5)	18.8 (15.6)	15.31 (17.0)	8.0 (16.8)
$\bar{x}$ % Time in DC6 (SD)	5.3 (6.0)	1.4 (1.6)	3.9 (8.6)	0.11 (0.5)
$\bar{x}$ % Time in DC7 (SD)	0.15 (0.3)	0 (0.1)	0.5 (1.3)	0 (0)
Mode of %Time in DC1	2.6	3.7	0	0
Mode of %Time in DC2	2.1	2.2	0.3	8.3
Mode of %Time in DC3	6.8	7.8	3.0	11.2
Mode of %Time in DC4	39.3	31.1	2.0	3.7
Mode of %Time in DC5	33.9	2.3	5.1	0.2
Mode of %Time in DC6	2.7	0	0	0
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	0, 27.9	0, 64.9	2.4, 48.7	0, 76.6
Minimum, Maximum % Time in DC2	0, 11.2	0, 24.0	1.6, 16.3	0, 27.5
Minimum, Maximum % Time in DC3	0.5, 23.7	2.3, 52.9	5.9, 25.3	0, 61.7
Minimum, Maximum % Time in DC4	3.1, 59.5	7.1, 73.9	15.2, 24.7	3.2, 76.8
Minimum, Maximum % Time in DC5	12.4, 60.8	0.4, 49.7	3.5, 57.3	0, 92.3
Minimum, Maximum % Time in DC6	0, 53.1	0, 5.3	0.2, 7.7	0, 3.5
Minimum, Maximum % Time in DC7	0, 2.1	0, 0.4	0, 0.3	0, 0
Overstory % Cover, $\bar{x} \pm$ SD	18.8 $\pm$ 33.8	27.4 $\pm$ 33.5	51.9 $\pm$ 42.8	15.4 $\pm$ 20.8
% Low Level Light Available, $\bar{x} \pm$SD[b]	67.4 $\pm$ 34.0	49.0 $\pm$ 32.5	43.8 $\pm$ 45.4	58.8 $\pm$ 33.3
% High Level Light Available, $\bar{x} \pm$SD[c]	73.4 $\pm$ 30.5	67.8 $\pm$ 29.7	50.8 $\pm$ 47.8	77.4 $\pm$ 28.6

Parameter	*Bidens mitis*	*Drosera intermedia*	*Brasenia schreberi*	*Lycopodium* spp.
Sample Size	59	35	13	22
Water Depth $\bar{x} \pm$ SD (m)	0.15 $\pm$ 0.08	0.17 $\pm$ 0.09	0.23 $\pm$ 0.06	0.15 $\pm$ 0.07
Minimum Water Depth (m)	-0.17	0.00	0.13	0.07
Maximum Water Depth (m)	0.36	0.35	0.30	0.40
$\bar{x}$ % Time in DC1 (SD) [a]	8.6 (14.8)	7.4 (10.0)	1.2 (2.2)	5.2 (4.2)
$\bar{x}$ % Time in DC2 (SD)	7.4 (6.3)	8.1 (6.9)	2.2 (2.8)	8.3 (5.5)
$\bar{x}$ % Time in DC3 (SD)	35.3 (17.1)	31.9 (21.2)	15.9 (15.1)	42.1 (13.1)
$\bar{x}$ % Time in DC4 (SD)	41.0 (20.1)	42.2 (22.1)	60.8 (11.1)	37.6 (15.8)
$\bar{x}$ % Time in DC5 (SD)	7.0 (11.8)	12.0 (15.8)	19.9 (16.5)	6.8 (19.2)
$\bar{x}$ % Time in DC6 (SD)	0.4 (2.7)	0.5 (1.5)	0 (0)	0 (0.1)
$\bar{x}$ % Time in DC7 (SD)	0.2 (1.5)	0 (0.1)	0 (0)	0 (0)
Mode of %Time in DC1	0	0	0	7.3
Mode of %Time in DC2	0	0	0	11.1
Mode of %Time in DC3	50.6	57.8	1.2	49.6
Mode of %Time in DC4	26.1	16.5	35.7	30.3
Mode of %Time in DC5	1.0	0.4	12.4	1.7
Mode of %Time in DC6	0	0	0	0
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	0, 78.6	0, 50.9	0, 7.3	0, 17.9
Minimum, Maximum % Time in DC2	0, 35.7	0, 22.8	0, 8.4	0, 24.0
Minimum, Maximum % Time in DC3	1.2, 58.2	2.2, 59.6	1.2, 50.2	0, 53.4
Minimum, Maximum % Time in DC4	1.6, 76.4	9.2, 79.9	35.7, 76.4	7.2, 70.4
Minimum, Maximum % Time in DC5	0, 74.0	0, 53.3	1.8, 46.2	0.5, 92.3
Minimum, Maximum % Time in DC6	0, 20.7	0, 7.9	0, 0	0, 0.4
Minimum, Maximum % Time in DC7	0, 11.4	0, 0.4	0, 0	0, 0
Overstory % Cover, $\bar{x} \pm$ SD	11.2 $\pm$ 24.1	18.7 $\pm$ 27.5	0.12 $\pm$ 0.4	3.7 $\pm$ 7.1
% Low Level Light Available, $\bar{x}$ $\pm$SD [b]	60.7 $\pm$ 30.7	58.1 $\pm$ 33.5	76.5 $\pm$ 18.8	65.2 $\pm$ 29.7
% High Level Light Available, $\bar{x}$ $\pm$SD [c]	81.8 $\pm$ 25.9	81.6 $\pm$ 23.6	89.8 $\pm$ 11.0	91.7 $\pm$ 10.3

Parameter	*Ludwigia alata*	*Itea virginica*	*Smilax walteri*	*Smilax laurifolia*
Sample Size	6	95	38	49
Water Depth $\bar{x} \pm$ SD (m)	0.29 ± 0.09	0.18 ± 0.27	0.06 ± 0.19	0.09 ± 0.14
Minimum Water Depth (m)	0.21	-0.45	-0.40	-0.29
Maximum Water Depth (m)	0.42	1.01	0.32	0.63
$\bar{x}$ % Time in DC1 (SD) [a]	29.0 (6.2)	26.6 (25.2)	34.7 (29.2)	25.0 (24.7)
$\bar{x}$ % Time in DC2 (SD)	3.6 (0.4)	6.5 (4.3)	7.7 (4.3)	10.2 (6.3)
$\bar{x}$ % Time in DC3 (SD)	7.4 (0.3)	16.5 (10.8)	17.9 (10.4)	31.7 (18.1)
$\bar{x}$ % Time in DC4 (SD)	11.9 (0.7)	21.4 (11.8)	22.4 (11.8)	25.0 (16.2)
$\bar{x}$ % Time in DC5 (SD)	20.1 (1.5)	18.5 (14.2)	15.4 (14.3)	5.4 (6.9)
$\bar{x}$ % Time in DC6 (SD)	18.2 (2.8)	6.5 (10.0)	1.6 (2.3)	1.4 (4.7)
$\bar{x}$ % Time in DC7 (SD)	9.9 (3.0)	4.0 (10.4)	0.3 (0.9)	1.3 (5.2)
Mode of %Time in DC1	19.4	25.0	26.4	6.7
Mode of %Time in DC2	3.7	2.6	13.0	10.1
Mode of %Time in DC3	7.3	27.5	25.9	49.1
Mode of %Time in DC4	12.3	25.9	25.2	32.1
Mode of %Time in DC5	18.9	0.9	9.1	1.9
Mode of %Time in DC6	15.3	0.9	0.5	0
Mode of %Time in DC7	8.1	0	0	0
Minimum, Maximum % Time in DC1	19.4, 35.1	0.5, 96.6	0, 95.0	0, 96.8
Minimum, Maximum % Time in DC2	2.9, 4.0	0.2, 16.3	0, 14.3	0.1, 35.7
Minimum, Maximum % Time in DC3	7.1, 8.0	1.4, 55.1	0.4, 49.1	0.8, 59.6
Minimum, Maximum % Time in DC4	10.7, 12.7	0.5, 43.6	1.0, 38.6	0.1, 80.5
Minimum, Maximum % Time in DC5	18.9, 22.6	0.2, 57.7	0.5, 66.3	0, 29.9
Minimum, Maximum % Time in DC6	15.3, 22.4	0, 33.6	0, 10.1	0, 22.6
Minimum, Maximum % Time in DC7	7.4, 13.8	0, 48.6	0, 4.2	0, 32.3
Overstory % Cover, $\bar{x} \pm$ SD	16.5 ± 33.9	47.3 ± 38.2	60.2 ± 37.5	47.9 ± 40.2
% Low Level Light Available, $\bar{x} \pm$ SD [b]	57.7 ± 23.8	33.9 ± 28.9	27.8 ± 28.9	33.7 ± 34.7
% High Level Light Available, $\bar{x} \pm$ SD [c]	76.0 ± 9.8	48.3 ± 33.1	37.3 ± 36.0	53.6 ± 38.0

Table 6-4--continued.

Parameter	*Cephalanthus occidentalis*	*Clethra alnifolia*	*Cyrilla racemiflora*	*Pierus phillyreifolia*
Sample Size	15	12	119	34
Water Depth $\bar{x} \pm$ SD (m)	0.20 ± 0.21	0.21 ± 0.17	0.11 ± 0.15	0.11 ± 0.15
Minimum Water Depth (m)	-0.38	0.01	-0.29	-0.28
Maximum Water Depth (m)	0.50	0.65	0.65	0.63
$\bar{x}$ % Time in DC1 (SD)[a]	33.8 (15.0)	14.4 (14.1)	25.2 (22.3)	26.5 (23.2)
$\bar{x}$ % Time in DC2 (SD)	4.7 (3.3)	7.6 (5.7)	8.4 (5.4)	9.9 (6.2)
$\bar{x}$ % Time in DC3 (SD)	9.4 (5.5)	23.4 (14.3)	22.9 (13.8)	24.6 (14.4)
$\bar{x}$ % Time in DC4 (SD)	12.8 (5.8)	31.9 (16.5)	26.6 (15.2)	25.6 (14.8)
$\bar{x}$ % Time in DC5 (SD)	17.4 (6.8)	17.4 (16.0)	14.7 (18.3)	11.2 (13.0)
$\bar{x}$ % Time in DC6 (SD)	13.6 (7.7)	2.6 (4.9)	1.5 (3.2)	1.3 (3.1)
$\bar{x}$ % Time in DC7 (SD)	8.3 (6.0)	2.8 (9.7)	0.6 (3.4)	1.0 (5.5)
Mode of %Time in DC1	33.1	0.7	0	26.4
Mode of %Time in DC2	2.8	2.0	0	13.0
Mode of %Time in DC3	7.5	4.6	25.9	22.6
Mode of %Time in DC4	12.3	7.1	25.2	25.2
Mode of %Time in DC5	19.4	0.8	0.8	9.1
Mode of %Time in DC6	0.4	0	0	0
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	15.2, 75.3	0.7, 50.0	0, 91.1	0, 94.8
Minimum, Maximum % Time in DC2	2.1, 14.1	2.0, 19.7	0, 27.5	0.1, 35.7
Minimum, Maximum % Time in DC3	5.0, 24.2	4.6, 49.1	0, 59.6	2.0, 53.6
Minimum, Maximum % Time in DC4	5.2, 27.0	7.1, 67.9	1.4, 79.9	0.7, 80.5
Minimum, Maximum % Time in DC5	5.9, 29.8	0.8, 52.8	0.1, 91.8	0, 51.9
Minimum, Maximum % Time in DC6	0.4, 23.6	0, 17.2	0, 17.24	0, 17.0
Minimum, Maximum % Time in DC7	0, 18.2	0, 33.7	0, 33.7	0, 32.3
Overstory % Cover, $\bar{x} \pm$ SD	32.9 ± 43.8	51.2 ± 41.8	42.11 ± 38.9	62.1 ± 38.0
% Low Level Light Available, $\bar{x} \pm$SD[b]	32.0 ± 34.4	22.3 ± 29.0	39.1 ± 36.8	18.6 ± 24.3
% High Level Light Available, $\bar{x} \pm$SD[c]	48.3 ± 34.9	49.5 ± 33.5	55.9 ± 37.4	37.9 ± 35.9

Parameter	*Lyonia lucida*	*Leucothoe racemosa*	*Gordonia lasianthus*	*Ilex cassine*
Sample Size	93	68	33	57
Water Depth $\bar{x} \pm$ SD (m)	0.07 ± 0.11	0.07 ± 0.11	0.08 ± 0.10	0.12 ± 0.16
Minimum Water Depth (m)	-0.40	-0.36	-0.10	-0.35
Maximum Water Depth (m)	0.30	0.38	0.32	0.58
$\bar{x}$ % Time in DC1 (SD) [a]	28.1 (24.3)	28.1 (23.6)	24.9 (21.8)	24.4 (20.8)
$\bar{x}$ % Time in DC2 (SD)	10.1 (5.8)	9.5 (3.9)	9.8 (5.0)	8.1 (4.9)
$\bar{x}$ % Time in DC3 (SD)	27.3 (14.7)	28.9 (15.0)	28.0 (13.5)	20.7 (11.8)
$\bar{x}$ % Time in DC4 (SD)	26.2 (15.4)	24.8 (11.7)	27.3 (13.1)	25.8 (13.0)
$\bar{x}$ % Time in DC5 (SD)	7.8 (9.3)	7.0 (6.6)	7.9 (11.2)	15.6 (14.4)
$\bar{x}$ % Time in DC6 (SD)	0.4 (0.9)	1.1 (3.4)	0.2 (0.5)	2.5 (5.0)
$\bar{x}$ % Time in DC7 (SD)	0 (0)	0.5 (2.3)	0 (0)	1.2 (4.6)
Mode of %Time in DC1	6.7	6.7	5.2	7.2
Mode of %Time in DC2	10.1	10.1	10.5	9.4
Mode of %Time in DC3	17.4	49.1	19.3	14.8
Mode of %Time in DC4	32.1	32.1	7.9	30.7
Mode of %Time in DC5	0.5	1.9	0.9	0.8
Mode of %Time in DC6	0	0	0	0
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	0, 96.8	1.5, 93.5	0.2, 63.7	0, 90.1
Minimum, Maximum % Time in DC2	0.1, 35.7	1.9, 27.5	0.4, 27.3	0, 24.0
Minimum, Maximum % Time in DC3	0.8, 59.6	2.4, 53.6	4.1, 49.6	0.2, 49.6
Minimum, Maximum % Time in DC4	0.1, 80.5	1.4, 60.7	7.9, 60.9	0.8, 60.9
Minimum, Maximum % Time in DC5	0, 45.2	0.4, 23.9	0.6, 60.8	0.3, 76.5
Minimum, Maximum % Time in DC6	0, 5.3	0, 20.5	0, 2.4	0, 23.5
Minimum, Maximum % Time in DC7	0, 0.3	0, 12.9	0, 0.2	0, 30.6
Overstory % Cover, $\bar{x} \pm$ SD	61.7 ± 36.9	54.0 ± 39.2	d	d
% Low Level Light Available, $\bar{x} \pm$ SD [b]	22.0 ± 28.8	29.2 ± 31.9		
% High Level Light Available, $\bar{x} \pm$ SD [c]	39.4 ± 36.6	43.8 ± 37.9		

Parameter	*Magnolia virginiana*	*Persea palustris*	*Pinus* spp.	*Nyssa sylvatica* v. *biflora*
Sample Size	20	7	12	34
Water Depth $\bar{x} \pm$ SD (m)	0.11 ± 0.13	0.11 ± 0.09	0.15 ± 0.11	0.22 ± 0.21
Minimum Water Depth (m)	-0.07	-0.06	-0.03	-0.32
Maximum Water Depth (m)	0.44	0.21	0.37	0.63
$\bar{x}$ % Time in DC1 (SD) [a]	26.9 (19.6)	25.6 (19.3)	13.5 (16.0)	26.5 (18.6)
$\bar{x}$ % Time in DC2 (SD)	9.7 (5.2)	8.0 (2.9)	11.0 (8.1)	4.3 (3.2)
$\bar{x}$ % Time in DC3 (SD)	23.0 (12.1)	20.5 (3.6)	27.0 (15.5)	10.4 (6.4)
$\bar{x}$ % Time in DC4 (SD)	24.4 (9.8)	30.1 (15.3)	30.1 (13.1)	18.2 (11.8)
$\bar{x}$ % Time in DC5 (SD)	12.8 (13.2)	14.8 (7.3)	18.2 (29.9)	22.3 (11.8)
$\bar{x}$ % Time in DC6 (SD)	2.3 (5.0)	1.0 (0.6)	0 (0)	10.3 (7.6)
$\bar{x}$ % Time in DC7 (SD)	0.9 (3.5)	0 (0)	0 (0)	7.4 (8.9)
Mode of %Time in DC1	3.8	1.6	0	23.6
Mode of %Time in DC2	2.2	3.1	0	3.9
Mode of %Time in DC3	7.0	14.8	0.1	7.4
Mode of %Time in DC4	9.8	12.9	13.9	10.9
Mode of %Time in DC5	0.6	4 4	5.2	19.2
Mode of %Time in DC6	0	0	0	1.8
Mode of %Time in DC7	0	0	0	0
Minimum, Maximum % Time in DC1	3.8, 61.2	1.6, 59.0	0, 51.9	1.9, 71.8
Minimum, Maximum % Time in DC2	2.2, 11.9	3.1, 11.4	0, 27.3	1.5, 18.1
Minimum, Maximum % Time in DC3	7.0, 46.9	14.8, 23.9	0.1, 45.6	3.9, 25.1
Minimum, Maximum % Time in DC4	9.8, 40.1	12.9, 60.9	13.9, 51.2	5.9, 38.3
Minimum, Maximum % Time in DC5	0.6, 46.2	4.4, 26.6	0.8, 85.9	7.3, 59.3
Minimum, Maximum % Time in DC6	0, 22.0	0, 1.7	0, 0.1	0.4, 23.5
Minimum, Maximum % Time in DC7	0, 15.5	0, 0.1	0, 0	0, 32.6
Overstory % Cover, $\bar{x} \pm$ SD	d	d	d	d

Parameter	*Acer rubrum*	*Taxodium ascendens*	*Nyssa ogeechee*	*Ilex myrtifolia*
Sample Size	8	93	6	3
Water Depth $\bar{x} \pm$ SD (m)	0.08 ± 0.19	0.17 ± 0.18	0.10 ± 0.21	0.09 ± 0.33
Minimum Water Depth (m)	-0.22	-0.35	-0.22	-0.22
Maximum Water Depth (m)	0.44	0.63	0.32	0.44
$\bar{x}$ % Time in DC1 (SD)[a]	40.0 (17.9)	22.2 (20.5)	42.9 (14.3)	43.8 (21.2)
$\bar{x}$ % Time in DC2 (SD)	4.4 (3.3)	5.9 (4.1)	3.0 (0.8)	2.6 (0.5)
$\bar{x}$ % Time in DC3 (SD)	9.8 (7.6)	15.5 (10.1)	6.0 (2.0)	5.1 (1.6)
$\bar{x}$ % Time in DC4 (SD)	13.6 (10.7)	25.5 (13.1)	8.7 (3.0)	7.6 (2.7)
$\bar{x}$ % Time in DC5 (SD)	15.4 (6.4)	23.0 (17.8)	15.5 (5.0)	14.5 (6.1)
$\bar{x}$ % Time in DC6 (SD)	9.7 (6.9)	4.3 (5.9)	13.9 (4.2)	14.2 (7.1)
$\bar{x}$ % Time in DC7 (SD)	7.2 (5.9)	2.6 (6.4)	10.1 (2.3)	12.2 (3.8)
Mode of %Time in DC1	9.2	0	26.6	20.2
Mode of %Time in DC2	2.1	2.2	2.1	2.2
Mode of %Time in DC3	3.9	7.4	3.9	3.9
Mode of %Time in DC4	5.9	10.9	5.9	5.9
Mode of %Time in DC5	8.0	19.2	10.4	10.4
Mode of %Time in DC6	0.4	0	8.3	8.3
Mode of %Time in DC7	0	0	6.7	8.1
Minimum, Maximum % Time in DC1	9.2, 61.3	0, 90.1	26.6, 61.3	20.2, 61.3
Minimum, Maximum % Time in DC2	2.1, 12.1	0, 18.1	2.1, 3.9	2.2, 3.1
Minimum, Maximum % Time in DC3	3.9, 23.3	0.1, 49.6	3.9, 8.0	3.9, 7.0
Minimum, Maximum % Time in DC4	5.9, 37.0	0.8, 60.9	5.9, 12.2	5.9, 10.7
Minimum, Maximum % Time in DC5	8.0, 26.8	0.3, 85.9	10.4, 21.1	10.4, 21.5
Minimum, Maximum % Time in DC6	0.4, 22.0	0, 22.0	8.3, 19.0	8.3, 22.0
Minimum, Maximum % Time in DC7	0, 15.5	0, 32.6	6.7, 13.1	8.1, 15.5
Overstory % Cover, $\bar{x} \pm$ SD	d	d	d	d

Table 6-4--continued.

Parameter	*Fraxinus caroliniana*
Sample Size	3
Water Depth $\bar{x} \pm$ SD (m)	0.26 ± 0.28
Minimum Water Depth (m)	-0.06
Maximum Water Depth (m)	0.44
$\bar{x}$ % Time in DC1 (SD) [a]	33.7 (21.9)
$\bar{x}$ % Time in DC2 (SD)	5.0 (3.1)
$\bar{x}$ % Time in DC3 (SD)	9.7 (4.4)
$\bar{x}$ % Time in DC4 (SD)	11.5 (1.2)
$\bar{x}$ % Time in DC5 (SD)	15.6 (9.7)
$\bar{x}$ % Time in DC6 (SD)	14.5 (12.3)
$\bar{x}$ % Time in DC7 (SD)	9.9 (8.6)
Mode of %Time in DC1	20.2
Mode of %Time in DC2	3.1
Mode of %Time in DC3	7.0
Mode of %Time in DC4	10.7
Mode of %Time in DC5	4.4
Mode of %Time in DC6	0.3
Mode of %Time in DC7	0
Minimum, Maximum % Time in DC1	20.2, 59.0
Minimum, Maximum % Time in DC2	3.1, 8.6
Minimum, Maximum % Time in DC3	7.0, 14.8
Minimum, Maximum % Time in DC4	10.7, 12.9
Minimum, Maximum % Time in DC5	4.4, 21.5
Minimum, Maximum % Time in DC6	0.3, 22.0
Minimum, Maximum % Time in DC7	0, 15.5
Overstory % Cover, $\bar{x} \pm$ SD	d

[a] Depth Classes (DC) are:

(no inundation)	DC 1	water depth $\leq$ 0.0 m
(shallow water)	DC 2	0.00 m < water depth $\leq$ 0.05 m
(shallow water)	DC 3	0.05 m < water depth $\leq$ 0.15 m
(shallow water)	DC 4	0.15 m < water depth $\leq$ 0.30 m
(deep water)	DC 5	0.30 m < water depth $\leq$ 0.60 m
(deep water)	DC 6	0.60 m < water depth $\leq$ 1.00 m
(deep water)	DC 7	water depth >1.00 m

[b] Light availability measured at 0.3 m above the peat surface with a Licor quantum sensor. See chapter text for details.

[c] Light availability measured at 1.0 m above the peat surface with a Licor quantum sensor. See chapter text for details.

[d] Overstory % cover and availability of light at 0.3 m and 1.0 m above the peat surface were not estimated for tree belt transects.

Table 6-5. *t*-test (mean water depth) and Wilcoxon rank-sum (percent of interval in each depth class) comparisons of hydrologic environments during 1962-1995 where species were present and absent in vegetation sample plots during 1993-1994.

Parameter	*Carex walteriana*	*Nymphaea odorata*	*Xyris* spp.	*Utricularia* spp.
Sample Size, Species Present	437	361	248	244
Sample Size, Species Absent	505	583	694	698
$\bar{x}$ Water Depth (SD) (m), Present	0.17 (0.14)	0.24 (0.13)	0.17 (0.12)	0.29 (0.13)
$\bar{x}$ Water Depth (SD) (m), Absent	0.22 (0.25)	0.17 (0.24)	0.21 (0.23)	0.17 (0.22)
P > t	0.0003	0.0001	0.0002	0.0001
$\bar{x}$ % Time in DC1 (SD), Present [a]	17.7 (20.8)	11.4 (16.0)	13.0 (18.9)	8.9 (12.2)
$\bar{x}$ % Time in DC1 (SD), Absent	22.1 (23.0)	25.4 (23.6)	22.6 (22.7)	24.0 (23.4)
P > Z	0.0216	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC2 (SD), Present	6.1 (4.3)	4.1 (3.7)	6.6 (5.4)	3.4 (2.9)
$\bar{x}$ % Time in DC2 (SD), Absent	5.3 (5.1)	6.6 (5.1)	5.3 (4.5)	6.5 (5.0)
P > Z	0.0001	0.0001	0.0010	0.0001
$\bar{x}$ % Time in DC3 (SD), Present	18.7 (12.5)	13.7 (12.2)	25.1 (16.9)	11.2 (9.5)
$\bar{x}$ % Time in DC3 (SD), Absent	14.7 (13.8)	18.3 (13.8)	13.5 (10.3)	18.4 (14.0)
P > Z	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC4 (SD), Present	30.5 (14.2)	30.2 (15.7)	36.0 (18.6)	29.1 (14.4)
$\bar{x}$ % Time in DC4 (SD), Absent	22.8 (16.7)	24.1 (15.8)	23.0 (13.5)	25.5 (16.5)
P > Z	0.0001	0.0001	0.0001	0.0002
$\bar{x}$ % Time in DC5 (SD), Present	24.8 (20.2)	37.1 (24.2)	18.3 (20.3)	41.8 (21.6)
$\bar{x}$ % Time in DC5 (SD), Absent	25.0 (23.3)	17.3 (16.2)	27.2 (22.0)	19.0 (18.7)
P > Z	0.4227	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC6 (SD), Present	2.1 (3.9)	3.3 (6.3)	1.0 (1.8)	4.8 (7.7)
$\bar{x}$ % Time in DC6 (SD), Absent	5.9 (8.5)	4.6 (7.4)	5.3 (7.8)	3.9 (6.8)
P > Zt	0.0002	0.5824	0.0001	0.0001
$\bar{x}$ % Time in DC7 (SD), Present	0.1 (0.8)	0.2 (1.1)	0.0 (0.1)	0.9 (5.0)
$\bar{x}$ % Time in DC7 (SD), Absent	4.2 (11.6)	3.6 (10.9)	3.1 (10.1)	2.8 (9.7)
P > Z	0.0001	0.0002	0.0001	0.8521
$\bar{x}$ Overstory % Cover (SD), Present	29.3 (36.8)	13.2 (27.1)	25.5 (35.1)	20.8 (34.1)
$\bar{x}$ Overstory % Cover (SD), Absent	27.4 (37.9)	37.6 (39.8)	29.3 (38.1)	30.9 (38.1)
P > Z	0.0266	0.0001	0.5831	0.0001
$\bar{x}$ % Low Level Light Available (SD), Present [b]	47.6 (35.0)	68.6 (34.3)	56.5 (35.5)	60.3 (38.8)
$\bar{x}$ % Low Level Light Available (SD), Absent	50.5 (39.2)	37.1 (33.9)	46.5 (37.6)	45.3 (36.0)
P > Z	0.1948	0.0001	0.0001	0.0001
$\bar{x}$ % High Level Light Available (SD), Present [c]	68.5 (33.3)	82.7 (25.6)	71.0 (33.0)	74.6 (30.7)
$\bar{x}$ % High Level Light Available (SD), Absent	66.3 (35.0)	57.8 (35.4)	66.0 (34.6)	64.8 (35.0)
P > Z	0.4431	0.0001	0.0070	0.0001

Parameter	*Eriocaulon lineare*	*Rhynchospora inundata*	*Eleocharis baldwinii/ vivipara*	*Panicum hemitomon*
Sample Size, Species Present	44	35	157	228
Sample Size, Species Absent	898	907	785	715
$\bar{x}$ Water Depth (SD) (m), Present	0.16 (0.08)	0.17 (0.13)	0.16 (0.20)	0.19 (0.15)
$\bar{x}$ Water Depth (SD) (m), Absent	0.20 (0.22)	0.20 (0.21)	0.21 (0.21)	0.20 (0.23)
P > t	0.0046	0.2700	0.0078	0.6135
$\bar{x}$ % Time in DC1 (SD), Present [a]	5.3 (9.0)	13.6 (21.8)	30.9 (21.5)	15.8 (20.0)
$\bar{x}$ % Time in DC1 (SD), Absent	20.8 (22.3)	20.3 (22.1)	17.9 (21.6)	21.4 (22.6)
P > Z	0.0001	0.0029	0.0001	0.0001
$\bar{x}$ % Time in DC2 (SD), Present	6.9 (4.7)	5.8 (7.2)	6.3 (5.0)	5.4 (4.8)
$\bar{x}$ % Time in DC2 (SD), Absent	5.6 (4.8)	5.7 (4.6)	5.5 (4.7)	5.7 (4.7)
P > Z	0.0385	0.3704	0.0225	0.2035
$\bar{x}$ % Time in DC3 (SD), Present	39.3 (19.7)	19.8 (17.6)	16.5 (13.3)	18.1 (14.9)
$\bar{x}$ % Time in DC3 (SD), Absent	15.4 (11.9)	16.4 (13.2)	16.6 (13.4)	16.1 (12.8)
P > Z	0.0001	0.5770	0.7395	0.2261
$\bar{x}$ % Time in DC4 (SD), Present	38.5 (19.2)	36.4 (21.9)	19.8 (15.6)	29.9 (16.4)
$\bar{x}$ % Time in DC4 (SD), Absent	25.8 (15.7)	26.0 (15.7)	27.7 (15.8)	25.3 (15.8)
P > Z	0.0001	0.0065	0.0001	0.0006
$\bar{x}$ % Time in DC5 (SD), Present	9.9 (21.4)	24.1 (25.1)	13.8 (11.5)	27.5 (24.0)
$\bar{x}$ % Time in DC5 (SD), Absent	25.6 (21.7)	24.9 (21.8)	27.1 (22.8)	24.1 (21.1)
P > Z	<0.0001	0.3981	0.0001	0.1138
$\bar{x}$ % Time in DC6 (SD), Present	0.0 (0.1)	0.2 (0.6)	7.1 (8.6)	2.8 (5.3)
$\bar{x}$ % Time in DC6 (SD), Absent	4.3 (7.1)	4.3 (7.1)	3.5 (6.5)	4.5 (7.5)
P > Zt	0.0001	0.0001	0.0528	0.0014
$\bar{x}$ % Time in DC7 (SD), Present	0.0 (0.0)	0.0 (0.0)	5.5 (8.3)	0.5 (2.3)
$\bar{x}$ % Time in DC7 (SD), Absent	2.4 (9.0)	2.4 (8.9)	1.7 (8.7)	2.9 (9.9)
P > Z	0.0001	0.0001	0.0001	0.0706
$\bar{x}$ Overstory % Cover (SD), Present	10.9 (16.9)	10.9 (17.5)	21.4 (32.7)	16.7 (28.5)
$\bar{x}$ Overstory % Cover (SD), Absent	29.2 (37.9)	29.0 (37.8)	29.7 (38.1)	32.0 (39.1)
P > Z	0.0154	0.1278	0.1166	0.0001
$\bar{x}$ % Low Level Light Available (SD), Present [b]	66.0 (33.3)	71.5 (30.1)	49.4 (35.0)	61.3 (34.9)
$\bar{x}$ % Low Level Light Available (SD), Absent	48.3 (37.3)	48.3 (37.3)	49.1 (35.0)	45.3 (37.2)
P > Z	0.0007	0.0006	0.6768	0.0001
$\bar{x}$ % High Level Light Available (SD), Present [c]	88.0 (18.1)	87.4 (19.7)	70.8 (29.4)	79.7 (25.9)
$\bar{x}$ % High Level Light Available (SD), Absent	66.3 (34.5)	66.6 (34.4)	66.6 (35.1)	63.4 (35.6)
P > Z	0.0001	0.0001	0.4921	0.0001

Parameter	*Lacnanthes caroliniana*	*Nuphar luteum*	*Woodwardia virginica*	*Peltandra virginica*
Sample Size, Species Present	266	68	197	356
Sample Size, Species Absent	676	874	745	586
$\bar{x}$ Water Depth (SD) (m), Present	0.10 (0.16)	0.26 (0.21)	0.12 (0.19)	0.15 (0.14)
$\bar{x}$ Water Depth (SD) (m), Absent	0.24 (0.22)	0.19 (0.21)	0.22 (0.21)	0.23 (0.24)
P > t	0.0001	0.0123	0.0001	0.0001
$\bar{x}$ % Time in DC1 (SD), Present [a]	28.5 (25.4)	23.0 (19.8)	25.0 (24.2)	19.8 (22.1)
$\bar{x}$ % Time in DC1 (SD), Absent	16.7 (19.7)	19.8 (22.3)	18.8 (21.4)	20.2 (22.2)
P > Z	0.0001	0.0914	0.0008	0.8028
$\bar{x}$ % Time in DC2 (SD), Present	7.5 (4.7)	3.5 (2.9)	8.5 (5.5)	6.9 (4.7)
$\bar{x}$ % Time in DC2 (SD), Absent	4.9 (4.6)	5.8 (4.8)	4.9 (4.2)	4.9 (4.6)
P > Z	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC3 (SD), Present	21.8 (15.0)	11.2 (11.3)	24.9 (15.8)	21.7 (14.4)
$\bar{x}$ % Time in DC3 (SD), Absent	14.5 (12.1)	17.0 (13.4)	14.3 (11.7)	13.4 (11.6)
P > Z	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC4 (SD), Present	25.0 (16.2)	22.5 (22.8)	26.0 (15.6)	30.2 (15.0)
$\bar{x}$ % Time in DC4 (SD), Absent	27.0 (15.9)	26.7 (15.4)	26.5 (16.2)	24.1 (16.2)
P > Z	0.0295	0.0001	0.5396	0.0001
$\bar{x}$ % Time in DC5 (SD), Present	13.4 (15.4)	20.6 (18.8)	13.3 (17.9)	19.8 (19.1)
$\bar{x}$ % Time in DC5 (SD), Absent	29.4 (22.4)	25.2 (22.1)	28.0 (21.8)	28.0 (22.9)
P > Z	0.0001	0.2710	0.0001	0.0001
$\bar{x}$ % Time in DC6 (SD), Present	2.4 (5.2)	11.0 (9.0)	1.7 (4.7)	1.5 (3.3)
$\bar{x}$ % Time in DC6 (SD), Absent	4.8 (7.5)	3.6 (6.6)	4.8 (7.4)	5.7 (8.1)
P > Zt	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC7 (SD), Present	1.3 (4.5)	8.2 (9.5)	0.6 (6.5)	0.0 (0.1)
$\bar{x}$ % Time in DC7 (SD), Absent	2.7 (9.3)	1.9 (8.5)	2.8 (9.2)	3.7 (10.9)
P > Z	0.0002	0.0001	0.0001	0.0001
$\bar{x}$ Overstory % Cover (SD), Present	28.6 (35.6)	9.6 (26.5)	39.6 (38.1)	32.8 (36.6)
$\bar{x}$ Overstory % Cover (SD), Absent	28.2 (38.1)	29.7 (37.7)	25.3 (36.6)	25.6 (37.6)
P > Z	0.0300	0.0001	0.0001	0.0001
$\bar{x}$ % Low Level Light Available (SD), Present [b]	45.7 (35.3)	48.9 (35.8)	33.2 (33.6)	44.8 (35.5)
$\bar{x}$ % Low Level Light Available (SD), Absent	50.5 (35.3)	49.2 (37.4)	53.4 (37.1)	51.8 (38.1)
P > Z	0.1714	0.3987	0.0001	0.0168
$\bar{x}$ % High Level Light Available (SD), Present [c]	69.0 (33.3)	77.7 (21.1)	59.4 (37.0)	64.5 (35.0)
$\bar{x}$ % High Level Light Available (SD), Absent	66.6 (34.6)	66.5 (34.9)	69.4 (33.2)	69.0 (33.7)
P > Z	0.2495	0.6409	0.0087	0.0354

Parameter	*Bidens mitis*	*Drosera intermedia*	*Brasenia schreberi*	*Lycopodium* spp.
Sample Size, Species Present	59	35	13	22
Sample Size, Species Absent	885	907	929	922
$\bar{x}$ Water Depth (SD) (m), Present	0.15 (0.08)	0.17 (0.09)	0.23 (0.06)	0.15 (0.06)
$\bar{x}$ Water Depth (SD) (m), Absent	0.20 (0.22)	0.20 (0.21)	0.20 (0.21)	0.20 (0.21)
P > t	0.0001	0.0469	0.1220	0.0019
$\bar{x}$ % Time in DC1 (SD), Present [a]	8.6 (14.8)	7.4 (10.0)	1.2 (2.2)	5.2 (4.2)
$\bar{x}$ % Time in DC1 (SD), Absent	20.8 (22.3)	20.5 (22.3)	20.3 (22.2)	20.4 (22.3)
P > Z	0.0001	0.0001	0.0001	0.0006
$\bar{x}$ % Time in DC2 (SD), Present	7.4 (7.3)	8.1 (6.9)	2.2 (2.8)	8.3 (5.5)
$\bar{x}$ % Time in DC2 (SD), Absent	5.5 (4.6)	5.6 (4.6)	5.7 (4.8)	5.6 (4.7)
P > Z	0.0149	0.0972	0.0006	0.0079
$\bar{x}$ % Time in DC3 (SD), Present	35.3 (17.1)	31.9 (21.2)	15.9 (15.1)	42.1 (13.1)
$\bar{x}$ % Time in DC3 (SD), Absent	15.3 (12.1)	16.0 (12.6)	16.6 (13.4)	15.9 (12.8)
P > Z	0.0001	0.0001	0.6802	0.0001
$\bar{x}$ % Time in DC4 (SD), Present	41.0 (20.1)	40.2 (22.1)	60.8 (11.1)	37.6 (15.8)
$\bar{x}$ % Time in DC4 (SD), Absent	25.4 (15.3)	25.9 (15.5)	25.9 (15.6)	26.1 (16.0)
P > Z	0.0001	0.0004	0.0001	0.0005
$\bar{x}$ % Time in DC5 (SD), Present	7.0 (11.8)	12.0 (15.8)	19.9 (16.5)	6.8 (19.2)
$\bar{x}$ % Time in DC5 (SD), Absent	26.1 (21.9)	25.4 (21.9)	25.0 (22.0)	25.3 (21.8)
P > Z	0.0001	0.0001	0.6017	0.0001
$\bar{x}$ % Time in DC6 (SD), Present	0.4 (2.7)	0.5 (1.5)	0.0 (0.0)	0.0 (0.1)
$\bar{x}$ % Time in DC6 (SD), Absent	4.4 (7.2)	4.3 (7.1)	4.1 (7.1)	4.2 (7.1)
P > Zt	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC7 (SD), Present	0.2 (1.5)	0.0 (0.1)	0.0 (0.0)	0.0 (0.0)
$\bar{x}$ % Time in DC7 (SD), Absent	2.5 (9.0)	2.4 (8.9)	2.3 (8.8)	2.4 (8.9)
P > Z	0.0001	0.0009	0.0177	0.0019
$\bar{x}$ Overstory % Cover (SD), Present	11.2 (24.1)	18.7 (27.5)	0.1 (0.4)	3.7 (7.1)
$\bar{x}$ Overstory % Cover (SD), Absent	29.4 (24.1)	28.7 (37.7)	28.7 (37.5)	28.9 (37.6)
P > Z	0.0003	0.2724	0.0002	0.0283
$\bar{x}$ % Low Level Light Available (SD), Present [b]	60.7 (30.7)	58.1 (33.5)	76.5 (18.8)	65.2 (29.7)
$\bar{x}$ % Low Level Light Available (SD), Absent	48.4 (37.6)	48.8 (37.4)	48.8 (37.4)	48.8 (37.4)
P > Z	0.0166	0.0979	0.0185	0.0271
$\bar{x}$ % High Level Light Available (SD), Present [c]	81.8 (25.9)	81.6 (23.6)	89.8 (11.0)	91.7 (10.3)
$\bar{x}$ % High Level Light Available (SD), Absent	66.4 (34.5)	66.8 (34.5)	67.0 (34.3)	66.7 (34.4)
P > Z	0.0001	0.0150	0.0134	0.0001

Parameter	*Sphagnum* spp.	*Andropogon virginica*	*Dulichium arendinaceum*	*Orontium aquaticum*
Sample Size, Species Present	310	61	162	133
Sample Size, Species Absent	634	881	780	809
$\bar{x}$ Water Depth (SD) (m), Present	0.18 (0.26)	0.17 (0.06)	0.18 (0.24)	0.26 (0.12)
$\bar{x}$ Water Depth (SD) (m), Absent	0.21 (0.18)	0.20 (0.22)	0.20 (0.20)	0.19 (0.22)
P > t	0.0441	0.0008	0.3078	0.0001
$\bar{x}$ % Time in DC1 (SD), Present [a]	20.4 (21.9)	5.8 (5.8)	20.6 (20.3)	10.2 (12.9)
$\bar{x}$ % Time in DC1 (SD), Absent	19.9 (22.3)	21.1 (22.5)	20.0 (22.5)	21.7 (22.9)
P > Z	0.9509	0.0001	0.2533	0.0001
$\bar{x}$ % Time in DC2 (SD), Present	7.7 (5.7)	6.5 (4.1)	6.8 (4.1)	4.2 (4.6)
$\bar{x}$ % Time in DC2 (SD), Absent	4.7 (3.8)	5.6 (4.8)	5.4 (4.9)	5.9 (4.7)
P > Z	0.0001	0.0337	0.0001	0.0001
$\bar{x}$ % Time in DC3 (SD), Present	24.4 (16.8)	34.9 (16.4)	21.7 (13.7)	12.8 (12.2)
$\bar{x}$ % Time in DC3 (SD), Absent	12.8 (9.2)	15.3 (12.2)	15.5 (13.1)	17.2 (13.5)
P > Z	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC4 (SD), Present	28.6 (18.9)	42.2 (16.6)	29.8 (17.2)	28.0 (14.1)
$\bar{x}$ % Time in DC4 (SD), Absent	25.3 (14.4)	25.3 (15.4)	25.7 (15.7)	26.1 (16.3)
P > Z	0.2937	0.0001	0.0121	0.1290
$\bar{x}$ % Time in DC5 (SD), Present	13.4 (17.4)	10.2 (14.0)	15.7 (14.9)	42.3 (25.5)
$\bar{x}$ % Time in DC5 (SD), Absent	30.5 (21.7)	25.9 (22.0)	26.8 (22.6)	22.0 (19.8)
P > Z	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC6 (SD), Present	2.5 (6.2)	0.4 (1.0)	2.7 (5.7)	2.6 (5.6)
$\bar{x}$ % Time in DC6 (SD), Absent	4.9 (7.3)	4.4 (7.2)	4.4 (7.2)	4.4 (7.2)
P > Zt	0.0001	0.0001	0.0001	0.7265
$\bar{x}$ % Time in DC7 (SD), Present	3.1 (13.1)	0.0 (0.0)	2.8 (12.7)	0.1 (0.2)
$\bar{x}$ % Time in DC7 (SD), Absent	1.9 (5.5)	2.5 (9.0)	2.2 (7.7)	2.7 (9.4)
P > Z	0.0001	0.0001	0.0086	0.0001
$\bar{x}$ Overstory % Cover (SD), Present	24.7 (34.0)	8.2 (19.5)	26.8 (35.7)	12.0 (25.3)
$\bar{x}$ Overstory % Cover (SD), Absent	30.1 (38.8)	29.7 (37.9)	28.6 (37.7)	31.0 (38.4)
P > Z	0.3263	0.0001	0.6994	0.0001
$\bar{x}$ % Low Level Light Available (SD), Present [b]	49.8 (36.3)	68.1 (28.7)	49.6 (35.2)	67.2 (37.3)
$\bar{x}$ % Low Level Light Available (SD), Absent	48.8 (37.8)	47.8 (37.5)	49.1 (37.7)	46.2 (36.5)
P > Z	0.4174	0.0001	0.9247	0.0001
$\bar{x}$ % High Level Light Available (SD), Present [c]	71.8 (32.6)	88.4 (18.0)	72.1 (31.1)	84.5 (25.5)
$\bar{x}$ % High Level Light Available (SD), Absent	65.2 (34.8)	65.8 (34.6)	66.3 (34.8)	64.5 (34.7)
P > Z	0.0006	0.0001	0.1117	0.0001

Parameter	*Saggetaria graminea*	*Tridenum virginicum*	*Sarracenia flava*	*Sarracenia psittacenia*
Sample Size, Species Present	66	42	62	15
Sample Size, Species Absent	878	902	882	927
$\bar{x}$ Water Depth (SD) (m), Present	0.15 (0.10)	0.14 (0.08)	0.13 (0.10)	0.12 (0.05)
$\bar{x}$ Water Depth (SD) (m), Absent	0.20 (0.22)	0.20 (0.22)	0.20 (0.22)	0.20 (0.21)
$P > t$	0.0006	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC1 (SD), Present [a]	14.9 (18.8)	7.9 (16.4)	10.1 (18.1)	8.4 (13.5)
$\bar{x}$ % Time in DC1 (SD), Absent	20.5 (22.3)	20.6 (22.2)	20.7 (22.2)	20.2 (22.2)
$P > Z$	0.0576	0.0001	0.0001	0.0231
$\bar{x}$ % Time in DC2 (SD), Present	6.9 (4.6)	6.7 (4.5)	8.6 (5.8)	8.4 (3.1)
$\bar{x}$ % Time in DC2 (SD), Absent	5.6 (4.8)	5.6 (4.8)	5.6 (4.6)	5.6 (4.8)
$P > Z$	0.0038	0.0729	0.0001	0.0021
$\bar{x}$ % Time in DC3 (SD), Present	26.8 (16.2)	36.6 (17.0)	38.8 (18.9)	47.8 (9.9)
$\bar{x}$ % Time in DC3 (SD), Absent	15.8 (12.8)	15.6 (12.4)	15.0 (11.4)	16.1 (12.8)
$P > Z$	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC4 (SD), Present	35.3 (16.9)	43.0 (20.2)	33.9 (18.1)	33.5 (9.7)
$\bar{x}$ % Time in DC4 (SD), Absent	25.7 (15.8)	25.6 (15.4)	25.9 (15.8)	26.3 (16.1)
$P > Z$	0.0001	0.0001	0.0003	0.0069
$\bar{x}$ % Time in DC5 (SD), Present	15.4 (16.1)	5.6 (7.7)	8.5 (19.4)	1.9 (1.4)
$\bar{x}$ % Time in DC5 (SD), Absent	25.6 (22.1)	25.8 (21.9)	26.0 (21.6)	25.3 (21.9)
$P > Z$	0.0002	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC6 (SD), Present	0.6 (1.0)	0.1 (0.6)	0.0 (0.2)	0.0 (0.0)
$\bar{x}$ % Time in DC6 (SD), Absent	4.4 (7.2)	4.3 (7.1)	4.4 (7.2)	4.2 (7.1)
$P > Zt$	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC7 (SD), Present	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
$\bar{x}$ % Time in DC7 (SD), Absent	2.5 (9.1)	2.4 (9.0)	2.4 (9.0)	2.4 (8.3)
$P > Z$	0.0001	0.0001	0.0001	0.0107
$\bar{x}$ Overstory % Cover (SD), Present	15.3 (26.5)	3.7 (10.6)	12.6 (16.7)	14.3 (22.6)
$\bar{x}$ Overstory % Cover (SD), Absent	29.3 (37.9)	29.4 (37.8)	29.4 (38.2)	28.6 (37.6)
$P > Z$	0.0402	0.0001	0.3523	0.5914
$\bar{x}$ % Low Level Light Available (SD), Present [b]	62.0 (30.6)	70.6 (27.3)	54.6 (31.4)	48.8 (27.5)
$\bar{x}$ % Low Level Light Available (SD), Absent	48.2 (37.6)	48.2 (37.4)	48.8 (37.7)	49.2 (37.5)
$P > Z$	0.0075	0.0001	0.1237	0.9331
$\bar{x}$ % High Level Light Available (SD), Present [c]	80.8 (23.7)	89.9 (17.1)	80.5 (24.9)	83.1 (28.1)
$\bar{x}$ % High Level Light Available (SD), Absent	66.3 (34.7)	66.3 (34.5)	66.4 (34.6)	67.0 (34.3)
$P > Z$	0.0016	0.0001	0.0013	0.0069

Parameter	*Eleocharis robbinsii*	*Iris virginiana*	*Decodon verticillatus*	*Rhynchospora chalerocephala/ wrightiana*
Sample Size, Species Present	91	43	26	44
Sample Size, Species Absent	851	899	916	898
x̄ Water Depth (SD) (m), Present	0.30 (0.07)	0.18 (0.08)	0.19 (0.14)	0.10 (0.14)
x̄ Water Depth (SD) (m), Absent	0.19 (0.22)	0.20 (0.22)	0.20 (0.21)	0.20 (0.21)
P > t	0.0001	0.1036	0.7533	0.0001
x̄ % Time in DC1 (SD), Present [a]	6.3 (4.5)	11.6 (10.8)	10.9 (16.5)	20.1 (27.8)
x̄ % Time in DC1 (SD), Absent	21.5 (22.7)	20.5 (22.4)	20.3 (22.2)	20.1 (21.8)
P > Z	0.0001	0.1866	0.0046	0.1007
x̄ % Time in DC2 (SD), Present	3.0 (1.6)	7.8 (5.2)	6.6 (7.6)	7.7 (5.7)
x̄ % Time in DC2 (SD), Absent	5.9 (4.9)	5.6 (4.7)	5.6 (4.7)	5.6 (4.7)
P > Z	0.0001	0.0025	0.9438	0.0149
x̄ % Time in DC3 (SD), Present	10.1 (4.4)	26.7 (14.2)	25.1 (18.7)	30.3 (18.7)
x̄ % Time in DC3 (SD), Absent	17.2 (13.8)	16.1 (13.1)	16.3 (13.1)	15.9 (12.7)
P > Z	0.0001	0.0001	0.0349	0.0001
x̄ % Time in DC4 (SD), Present	30.7 (7.2)	33.7 (12.2)	37.6 (23.6)	33.6 (23.0)
x̄ % Time in DC4 (SD), Absent	25.9 (16.6)	26.1 (16.1)	26.1 (15.7)	26.0 (15.6)
P > Z	0.0001	0.0001	0.0202	0.0408
x̄ % Time in DC5 (SD), Present	44.5 (9.5)	18.8 (15.6)	15.3 (17.0)	8.0 (16.8)
x̄ % Time in DC5 (SD), Absent	22.8 (21.8)	25.2 (22.1)	25.2 (22.0)	25.7 (21.8)
P > Z	0.0001	0.1350	0.0208	0.0001
x̄ % Time in DC6 (SD), Present	5.3 (6.0)	1.4 (1.6)	3.9 (8.6)	0.1 (0.5)
x̄ % Time in DC6 (SD), Absent	4.0 (7.1)	4.3 (7.2)	4.1 (7.0)	4.3 (7.1)
P > Zt	0.0001	0.0806	0.0030	0.0001
x̄ % Time in DC7 (SD), Present	0.2 (0.3)	0.0 (0.1)	0.5 (1.3)	0.0 (0.0)
x̄ % Time in DC7 (SD), Absent	2.5 (9.2)	2.4 (9.0)	2.4 (8.9)	2.4 (9.0)
P > Z	0.0009	0.0909	0.4237	0.0001
x̄ Overstory % Cover (SD), Present	18.8 (33.8)	27.4 (33.5)	20.5 (34.0)	15.4 (20.8)
x̄ Overstory % Cover (SD), Absent	29.3 (37.6)	28.3 (37.6)	28.5 (37.5)	29.0 (37.9)
P > Z	0.0024	0.2301	0.3314	0.4724
x̄ % Low Level Light Available (SD), Present [b]	67.4 (34.0)	49.0 (32.5)	54.7 (35.0)	58.8 (33.3)
x̄ % Low Level Light Available (SD), Absent	47.2 (34.0)	49.2 (37.5)	49.0 (37.4)	48.7 (37.4)
P > Z	0.0001	0.7768	0.5651	0.0310
x̄ % High Level Light Available (SD), Present [c]	73.4 (30.5)	67.8 (29.7)	72.6 (34.9)	74.4 (28.6)
x̄ % High Level Light Available (SD), Absent	66.7 (34.5)	67.3 (34.4)	67.2 (34.2)	66.8 (34.4)
P > Z	0.3230	0.3708	0.2912	0.0072

Parameter	*Ludwigia alata*	*Itea virginica*	*Smilax walteri*	*Smilax laurifolia*
Sample Size, Species Present	6	95	38	49
Sample Size, Species Absent	938	828	451	440
$\bar{x}$ Water Depth (SD) (m), Present	0.29 (0.09)	0.18 (0.27)	0.06 (0.19)	0.09 (0.14)
$\bar{x}$ Water Depth (SD) (m), Absent	0.20 (0.21)	0.20 (0.20)	0.19 (0.16)	0.19 (0.17)
$P > t$	0.2767	0.5085	<0.0001	0.0001
$\bar{x}$ % Time in DC1 (SD), Present [a]	29.0 (6.2)	26.6 (25.2)	34.7 (29.2)	25.0 (24.7)
$\bar{x}$ % Time in DC1 (SD), Absent	20.0 (22.2)	18.9 (21.2)	19.5 (20.4)	20.2 (21.1)
$P > Z$	0.0394	0.0001	0.0001	0.1116
$\bar{x}$ % Time in DC2 (SD), Present	3.6 (0.4)	6.5 (4.3)	7.7 (4.3)	10.2 (6.3)
$\bar{x}$ % Time in DC2 (SD), Absent	5.7 (4.8)	5.5 (4.7)	5.6 (4.5)	5.2 (4.0)
$P > Z$	0.4708	0.0068	0.0012	0.0001
$\bar{x}$ % Time in DC3 (SD), Present	7.4 (0.3)	16.5 (10.8)	17.9 (10.4)	31.7 (18.1)
$\bar{x}$ % Time in DC3 (SD), Absent	16.6 (13.4)	16.5 (13.7)	17.2 (13.4)	15.6 (11.4)
$P > Z$	0.0491	0.1623	0.1199	0.0001
$\bar{x}$ % Time in DC4 (SD), Present	11.9 (0.7)	21.4 (11.8)	22.4 (11.8)	25.0 (16.2)
$\bar{x}$ % Time in DC4 (SD), Absent	26.5 (16.1)	27.0 (16.3)	27.1 (14.9)	26.9 (14.5)
$P > Z$	0.0181	0.0067	0.0986	0.1341
$\bar{x}$ % Time in DC5 (SD), Present	20.0 (1.5)	18.5 (14.2)	15.4 (14.3)	5.4 (6.9)
$\bar{x}$ % Time in DC5 (SD), Absent	24.9 (22.0)	25.9 (22.5)	24.8 (21.1)	26.1 (20.8)
$P > Z$	0.9838	0.0200	0.0073	0.0001
$\bar{x}$ % Time in DC6 (SD), Present	18.2 (2.8)	6.5 (10.0)	1.6 (2.3)	1.4 (4.7)
$\bar{x}$ % Time in DC6 (SD), Absent	4.0 (7.0)	3.9 (6.6)	4.0 (5.9)	4.0 (5.8)
$P > Zt$	0.0002	0.0010	0.5023	0.0001
$\bar{x}$ % Time in DC7 (SD), Present	9.9 (3.0)	4.0 (10.4)	0.3 (0.9)	1.3 (5.2)
$\bar{x}$ % Time in DC7 (SD), Absent	2.3 (8.8)	2.2 (8.6)	1.9 (5.4)	1.8 (5.2)
$P > Z$	0.0001	0.1555	0.0762	0.0012
$\bar{x}$ Overstory % Cover (SD), Present	16.5 (33.9)	47.3 (38.2)	60.2 (37.5)	47.9 (40.2)
$\bar{x}$ Overstory % Cover (SD), Absent	28.4 (37.4)	25.7 (36.4)	27.9 (37.7)	28.5 (38.0)
$P > Z$	0.3977	0.0001	0.0001	0.0004
$\bar{x}$ % Low Level Light Available (SD), Present [b]	57.7 (23.8)	33.9 (28.9)	27.8 (28.9)	33.7 (34.7)
$\bar{x}$ % Low Level Light Available (SD), Absent	49.1 (37.4)	50.8 (37.7)	50.4 (37.6)	50.3 (37.4)
$P > Z$	0.6619	0.0001	0.0009	0.0139
$\bar{x}$ % High Level Light Available (SD), Present [c]	76.0 (9.8)	48.3 (33.1)	37.3 (36.0)	53.6 (38.0)
$\bar{x}$ % High Level Light Available (SD), Absent	67.3 (34.3)	69.6 (33.5)	67.9 (33.9)	66.9 (34.4)
$P > Z$	0.5568	0.0001	0.0001	0.0354

Parameter	*Cephalanthus occidentalis*	*Clethra alnifolia*	*Cyrilla racemiflora*	*Pierus phillyreifolia*
Sample Size, Species Present	15	12	119	34
Sample Size, Species Absent	474	477	370	455
$\bar{x}$ Water Depth (SD) (m), Present	0.21 (0.19)	0.20 (0.16)	0.09 (0.12)	0.11 (0.15)
$\bar{x}$ Water Depth (SD) (m), Absent	0.18 (0.17)	0.18 (0.17)	0.21 (0.17)	0.18 (0.17)
$P > t$	0.4011	0.7048	0.0001	0.0170
$\bar{x}$ % Time in DC1 (SD), Present [a]	31.1 (15.0)	15.3 (11.0)	26.6 (21.4)	26.5 (23.2)
$\bar{x}$ % Time in DC1 (SD), Absent	20.4 (21.6)	20.8 (21.7)	18.8 (21.3)	20.3 (21.4)
$P > Z$	0.0023	0.8604	0.0001	0.0470
$\bar{x}$ % Time in DC2 (SD), Present	4.5 (2.8)	9.0 (6.4)	9.0 (4.7)	9.9 (6.2)
$\bar{x}$ % Time in DC2 (SD), Absent	5.8 (4.5)	5.7 (4.4)	4.7 (3.9)	5.4 (4.2)
$P > Z$	0.4708	0.0400	0.0001	0.0001
$\bar{x}$ % Time in DC3 (SD), Present	9.9 (6.3)	26.2 (15.4)	26.0 (13.5)	24.6 (14.4)
$\bar{x}$ % Time in DC3 (SD), Absent	17.4 (13.2)	17.0 (13.0)	14.4 (11.7)	16.7 (12.9)
$P > Z$	0.0152	0.0155	0.0001	0.0001
$\bar{x}$ % Time in DC4 (SD), Present	13.7 (7.3)	28.3 (11.8)	26.7 (13.6)	25.6 (14.8)
$\bar{x}$ % Time in DC4 (SD), Absent	27.1 (14.7)	26.7 (14.8)	26.7 (15.1)	26.8 (14.7)
$P > Z$	0.0001	0.6935	0.5843	0.3374
$\bar{x}$ % Time in DC5 (SD), Present	18.8 (5.9)	16.0 (15.9)	10.0 (10.0)	11.2 (13.1)
$\bar{x}$ % Time in DC5 (SD), Absent	24.2 (21.1)	24.2 (20.9)	28.5 (21.4)	25.0 (21.0)
$P > Z$	0.7950	0.1735	0.0001	0.0001
$\bar{x}$ % Time in DC6 (SD), Present	13.7 (7.4)	2.5 (4.8)	1.0 (2.3)	1.3 (3.1)
$\bar{x}$ % Time in DC6 (SD), Absent	3.5 (5.4)	3.8 (5.8)	4.7 (6.2)	4.0 (5.9)
$P > Zt$	0.0001	0.4850	0.0001	0.0094
$\bar{x}$ % Time in DC7 (SD), Present	8.3 (5.8)	2.7 (9.3)	0.6 (3.3)	1.0 (5.5)
$\bar{x}$ % Time in DC7 (SD), Absent	1.6 (5.1)	1.8 (5.1)	2.2 (5.7)	1.9 (5.2)
$P > Z$	0.0001	0.5268	0.0001	0.0061
$\bar{x}$ Overstory % Cover (SD), Present	38.8 (49.2)	54.3 (38.5)	45.4 (39.5)	62.1 (38.0)
$\bar{x}$ Overstory % Cover (SD), Absent	30.2 (38.2)	29.8 (38.4)	25.6 (37.1)	28.1 (37.6)
$P > Z$	0.9257	0.0275	0.0001	0.0001
$\bar{x}$ % Low Level Light Available (SD), Present [b]	38.7 (35.9)	29.1 (32.9)	31.8 (31.9)	18.6 (24.3)
$\bar{x}$ % Low Level Light Available (SD), Absent	48.9 (37.5)	49.1 (37.5)	54.0 (37.6)	50.8 (37.3)
$P > Z$	0.2215	0.1688	0.0001	0.0001
$\bar{x}$ % High Level Light Available (SD), Present [c]	53.7 (32.9)	41.6 (37.7)	52.7 (37.4)	37.9 (35.9)
$\bar{x}$ % High Level Light Available (SD), Absent	65.9 (35.0)	66.2 (34.7)	69.7 (37.4)	67.6 (34.1)
$P > Z$	0.0130	0.0352	0.0001	0.0001

Parameter	*Lyonia lucida*	*Leucothoe racemosa*	*Gordonia lasianthus*	*Ilex cassine*
Sample Size, Species Present	93	68	33	57
Sample Size, Species Absent	396	421	133	109
$\bar{x}$ Water Depth (SD) (m), Present	0.07 (0.12)	0.07 (0.11)	0.08 (0.10)	0.12 (0.16)
$\bar{x}$ Water Depth (SD) (m), Absent	0.20 (0.17)	0.19 (0.17)	0.20 (0.16)	0.20 (0.15)
P > t	0.0001	0.0001	0.0001	0.0020
$\bar{x}$ % Time in DC1 (SD), Present [a]	28.1 (24.3)	28.1 (23.6)	24.9 (21.8)	24.4 (20.8)
$\bar{x}$ % Time in DC1 (SD), Absent	19.0 (20.5)	19.5 (21.0)	18.4 (18.6)	17.3 (18.2)
P > Z	0.0001	0.0005	0.2010	0.0048
$\bar{x}$ % Time in DC2 (SD), Present	10.1 (5.8)	9.5 (3.9)	9.8 (5.0)	8.1 (4.9)
$\bar{x}$ % Time in DC2 (SD), Absent	4.7 (3.4)	5.1 (4.3)	5.2 (3.8)	5.0 (3.8)
P > Z	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC3 (SD), Present	27.3 (14.7)	28.9 (15.0)	28.0 (13.5)	20.7 (11.8)
$\bar{x}$ % Time in DC3 (SD), Absent	14.8 (11.5)	15.3 (11.8)	14.9 (10.3)	15.8 (12.0)
P > Z	0.0001	0.0001	0.0001	0.0006
$\bar{x}$ % Time in DC4 (SD), Present	26.2 (15.4)	24.8 (11.7)	27.2 (13.1)	25.8 (13.0)
$\bar{x}$ % Time in DC4 (SD), Absent	26.9 (15.4)	27.0 (15.1)	26.6 (13.0)	27.2 (13.0)
P > Z	0.1486	0.2588	0.9419	0.3914
$\bar{x}$ % Time in DC5 (SD), Present	7.8 (9.3)	7.0 (6.6)	7.9 (11.2)	15.6 (14.4)
$\bar{x}$ % Time in DC5 (SD), Absent	27.9 (20.9)	26.8 (21.0)	27.9 (19.9)	28.3 (21.4)
P > Z	0.0001	0.0001	0.0001	0.0001
$\bar{x}$ % Time in DC6 (SD), Present	0.4 (0.9)	1.1 (3.4)	0.2 (0.5)	2.5 (5.0)
$\bar{x}$ % Time in DC6 (SD), Absent	4.6 (6.1)	4.2 (5.9)	4.4 (5.9)	4.2 (5.7)
P > Zt	0.0001	0.0001	0.0001	0.0142
$\bar{x}$ % Time in DC7 (SD), Present	0.0 (0.0)	0.5 (2.3)	0.0 (0.0)	1.9 (5.3)
$\bar{x}$ % Time in DC7 (SD), Absent	2.2 (5.7)	2.0 (5.5)	2.1 (5.6)	1.2 (4.6)
P > Z	0.0001	0.0001	0.0005	0.0117
$\bar{x}$ Overstory % Cover (SD), Present	61.7 (36.9)	54.0 (39.2)	d	d
$\bar{x}$ Overstory % Cover (SD), Absent	23.1 (35.2)	26.6 (37.2)		
P > Z	0.0001	0.0001		
$\bar{x}$ % Low Level Light Available (SD), Present [b]	22.0 (28.8)	29.2 (31.9)		
$\bar{x}$ % Low Level Light Available (SD), Absent	54.8 (36.6)	51.7 (37.4)		
P > Z	0.0001	0.0001		
$\bar{x}$ % High Level Light Available (SD), Present [c]	39.4 (36.6)	43.8 (37.9)		
$\bar{x}$ % High Level Light Available (SD), Absent	71.7 (31.7)	69.1 (33.2)		
P > Z	0.0001	0.0001		

Parameter	*Magnolia virginiana*	*Persea palustris*	*Pinus* spp.	*Nyssa sylvatica* v. *biflora*
Sample Size, Species Present	20	7	12	34
Sample Size, Species Absent	146	159	154	132
$\bar{x}$ Water Depth (SD) (m), Present	0.11 (0.13)	0.11 (0.09)	0.15 (0.11)	0.22 (0.21)
$\bar{x}$ Water Depth (SD) (m), Absent	0.19 (0.16)	0.18 (0.16)	0.18 (0.16)	0.17 (0.21)
P > t	0.0572	0.2928	0.5773	0.1549
$\bar{x}$ % Time in DC1 (SD), Present [a]	26.9 (19.6)	25.6 (19.3)	13.5 (16.0)	26.5 (18.6)
$\bar{x}$ % Time in DC1 (SD), Absent	18.7 (19.2)	19.4 (19.4)	20.2 (19.6)	17.9 (19.2)
P > Z	0.0356	0.2589	0.1625	0.0020
$\bar{x}$ % Time in DC2 (SD), Present	9.7 (5.2)	8.0 (2.9)	11.0 (8.1)	4.3 (3.2)
$\bar{x}$ % Time in DC2 (SD), Absent	5.6 (4.1)	6.0 (4.5)	5.7 (3.8)	6.5 (4.6)
P > Z	0.0002	0.0819	0.0103	0.0059
$\bar{x}$ % Time in DC3 (SD), Present	23.0 (12.1)	20.5 (3.6)	27.0 (15.5)	10.4 (6.4)
$\bar{x}$ % Time in DC3 (SD), Absent	16.7 (12.0)	17.3 (12.4)	16.7 (11.6)	19.3 (12.6)
P > Z	0.0127	0.0908	0.0109	0.0001
$\bar{x}$ % Time in DC4 (SD), Present	24.4 (9.8)	30.1 (15.3)	30.1 (13.1)	18.2 (11.3)
$\bar{x}$ % Time in DC4 (SD), Absent	27.0 (13.3)	26.5 (12.9)	26.4 (13.0)	28.9 (12.4)
P > Z	0.4273	0.8002	0.3577	0.0001
$\bar{x}$ % Time in DC5 (SD), Present	12.8 (13.2)	14.8 (7.3)	18.2 (29.9)	22.3 (11.8)
$\bar{x}$ % Time in DC5 (SD), Absent	25.4 (20.5)	24.3 (20.5)	24.4 (19.3)	24.3 (21.8)
P > Z	0.0042	0.3682	0.0254	0.5470
$\bar{x}$ % Time in DC6 (SD), Present	2.3 (5.0)	1.0 (0.6)	0.0 (0.0)	10.3 (7.6)
$\bar{x}$ % Time in DC6 (SD), Absent	3.8 (5.0)	3.7 (5.6)	3.9 (5.6)	1.8 (3.0)
P > Zt	0.1678	0.6145	0.0001	0.0001
$\bar{x}$ % Time in DC7 (SD), Present	0.9 (3.5)	0.0 (0.0)	0.0 (0.0)	7.4 (8.9)
$\bar{x}$ % Time in DC7 (SD), Absent	1.8 (5.3)	1.7 (5.2)	1.8 (5.2)	0.2 (1.4)
P > Z	0.4459	0.2620	0.0197	0.0001
$\bar{x}$ Overstory % Cover (SD), Present $\bar{x}$ Overstory % Cover (SD), Absent P > Z	d	d	d	d

Parameter	*Acer rubrum*	*Taxodium ascendens*	*Nyssa ogeechee*	*Ilex myrtifolia*
Sample Size, Species Present	8	93	6	3
Sample Size, Species Absent	158	73	160	163
$\bar{x}$ Water Depth (SD) (m), Present	0.08 (0.19)	0.17 (0.16)	0.10 (0.21)	0.09 (0.33)
$\bar{x}$ Water Depth (SD) (m), Absent	0.18 (0.16)	0.18 (0.13)	0.18 (0.16)	0.18 (0.16)
P > t	0.0873	0.5789	0.2124	0.6811
$\bar{x}$ % Time in DC1 (SD), Present [a]	40.0 (17.9)	22.2 (20.5)	42.9 (14.3)	43.8 (21.2)
$\bar{x}$ % Time in DC1 (SD), Absent	18.7 (18.9)	16.5 (17.5)	18.8 (19.0)	19.3 (19.1)
P > Z	0.0029	0.0338	0.0029	0.0495
$\bar{x}$ % Time in DC2 (SD), Present	4.4 (3.3)	5.9 (4.1)	3.0 (0.8)	2.6 (0.5)
$\bar{x}$ % Time in DC2 (SD), Absent	6.2 (4.5)	6.3 (4.8)	6.2 (4.5)	6.2 (4.5)
P > Z	0.2471	0.6324	0.0390	0.0788
$\bar{x}$ % Time in DC3 (SD), Present	9.8 (7.6)	15.5 (10.1)	6.0 (2.0)	5.1 (1.6)
$\bar{x}$ % Time in DC3 (SD), Absent	17.9 (12.2)	20.0 (14.0)	17.9 (12.2)	17.7 (12.1)
P > Z	0.0371	0.1392	0.0025	0.0190
$\bar{x}$ % Time in DC4 (SD), Present	13.6 (10.7)	25.5 (13.1)	8.7 (3.0)	7.6 (2.7)
$\bar{x}$ % Time in DC4 (SD), Absent	27.4 (12.7)	28.2 (12.7)	27.4 (12.7)	27.0 (12.8)
P > Z	0.0028	0.2956	0.0004	0.0081
$\bar{x}$ % Time in DC5 (SD), Present	15.4 (6.4)	23.0 (17.8)	15.5 (5.0)	14.5 (6.1)
$\bar{x}$ % Time in DC5 (SD), Absent	24.3 (20.5)	25.1 (22.9)	24.2 (20.4)	24.1 (20.3)
P > Z	0.3838	0.8785	0.4861	0.5444
$\bar{x}$ % Time in DC6 (SD), Present	9.7 (6.9)	4.3 (5.9)	13.9 (4.2)	14.2 (7.1)
$\bar{x}$ % Time in DC6 (SD), Absent	3.3 (5.3)	2.7 (4.9)	3.2 (5.2)	3.4 (5.3)
P > Zt	0.0033	0.0030	0.0003	0.0116
$\bar{x}$ % Time in DC7 (SD), Present	7.2 (5.9)	2.6 (6.4)	10.1 (2.3)	12.2 (3.8)
$\bar{x}$ % Time in DC7 (SD), Absent	1.4 (4.9)	0.5 (2.2)	1.3 (4.9)	1.5 (4.9)
P > Z	0.0006	0.0363	0.0001	0.0010
$\bar{x}$ Overstory % Cover (SD), Present $\bar{x}$ Overstory % Cover (SD), Absent P > Z	d	d	d	d

Parameter	*Fraxinus caroliniana*
Sample Size, Species Present	3
Sample Size, Species Absent	163
$\bar{x}$ Water Depth (SD) (m), Present	0.26 (0.28)
$\bar{x}$ Water Depth (SD) (m), Absent	0.17 (0.16)
P > t	0.3607
$\bar{x}$ % Time in DC1 (SD), Present [a]	33.7 (21.9)
$\bar{x}$ % Time in DC1 (SD), Absent	19.4 (19.3)
P > Z	0.1526
$\bar{x}$ % Time in DC2 (SD), Present	5.0 (3.1)
$\bar{x}$ % Time in DC2 (SD), Absent	6.1 (4.5)
P > Z	0.7297
$\bar{x}$ % Time in DC3 (SD), Present	9.7 (4.4)
$\bar{x}$ % Time in DC3 (SD), Absent	17.6 (12.2)
P > Z	0.1824
$\bar{x}$ % Time in DC4 (SD), Present	11.5 (1.2)
$\bar{x}$ % Time in DC4 (SD), Absent	27.0 (12.9)
P > Z	0.0300
$\bar{x}$ % Time in DC5 (SD), Present	15.6 (9.7)
$\bar{x}$ % Time in DC5 (SD), Absent	24.1 (20.3)
P > Z	0.6278
$\bar{x}$ % Time in DC6 (SD), Present	14.5 (12.3)
$\bar{x}$ % Time in DC6 (SD), Absent	3.4 (5.2)
P > Zt	0.0980
$\bar{x}$ % Time in DC7 (SD), Present	9.9 (8.6)
$\bar{x}$ % Time in DC7 (SD), Absent	1.5 (4.9)
P > Z	0.0537
$\bar{x}$ Overstory % Cover (SD), Present	d
$\bar{x}$ Overstory % Cover (SD), Absent	
P > Z	

[a] Depth Classes (DC) are:

(no inundation)	DC 1	water depth $\leq$ 0.0 m
(shallow water)	DC 2	0.00 m < water depth $\leq$ 0.05 m
(shallow water)	DC 3	0.05 m < water depth $\leq$ 0.15 m
(shallow water)	DC 4	0.15 m < water depth $\leq$ 0.30 m
(deep water)	DC 5	0.30 m < water depth $\leq$ 0.60 m
(deep water)	DC 6	0.60 m < water depth $\leq$ 1.00 m
(deep water)	DC 7	water depth >1.00 m

[b] Light availability measured at 0.3 m above the peat surface with a Licor quantum sensor. See chapter text for details.

[c] Light availability measured at 1.0 m above the peat surface with a Licor quantum sensor. See chapter text for details.

[d] Overstory % cover and availability of light at 0.3 m and 1.0 m above the peat surface were not estimated for tree belt transects.

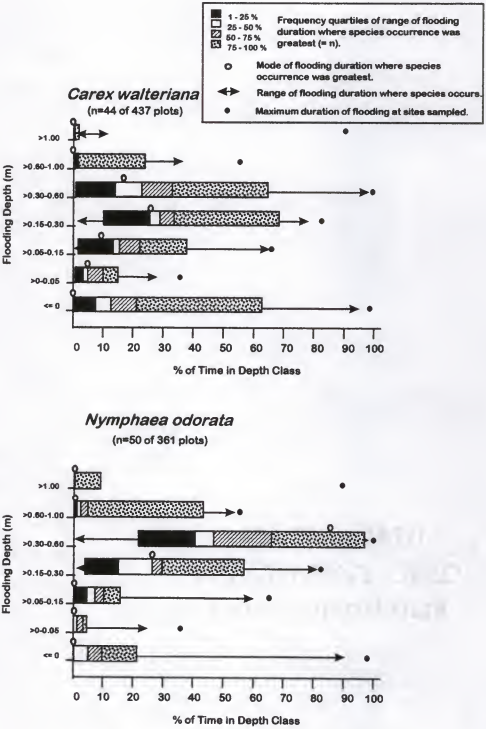


Figure 6-7. Hydrologic conditions where species occurred at greatest abundance (90-100% maximum density or percent cover).

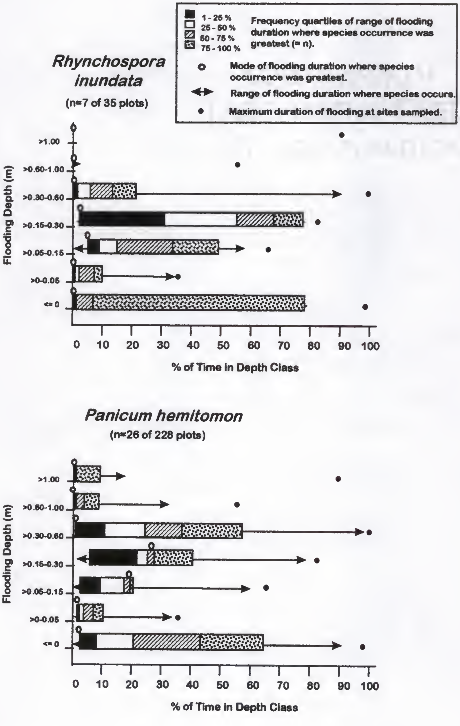
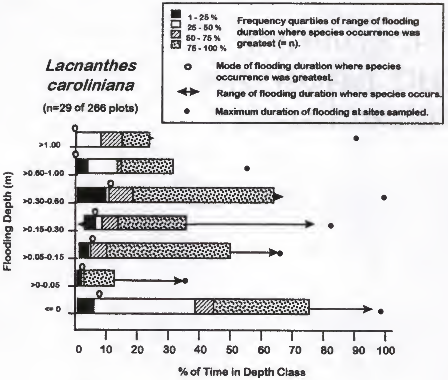


Figure 6-7--continued.



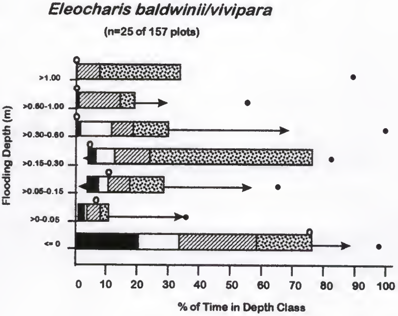
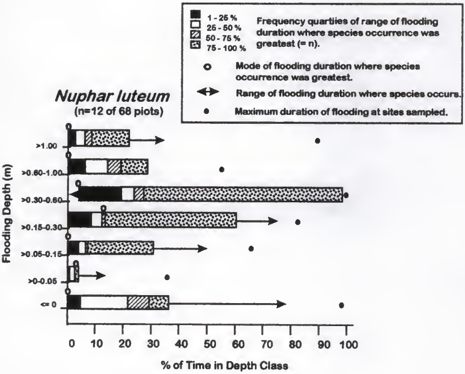


Figure 6-7--continued.



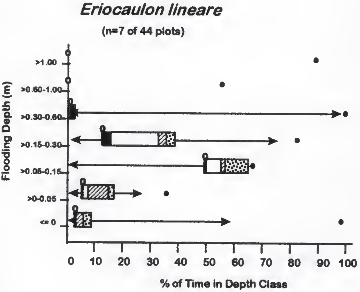
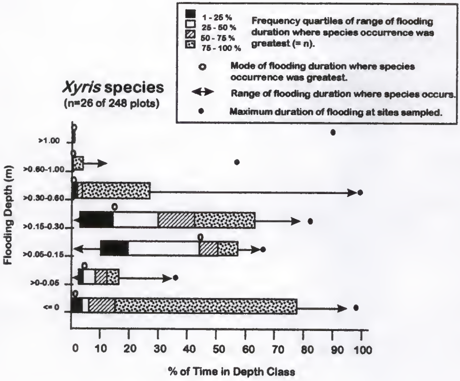


Figure 6-7--continued.



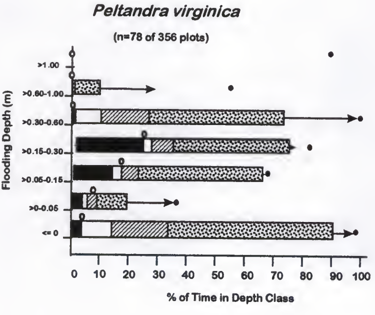


Figure 6-7--continued.

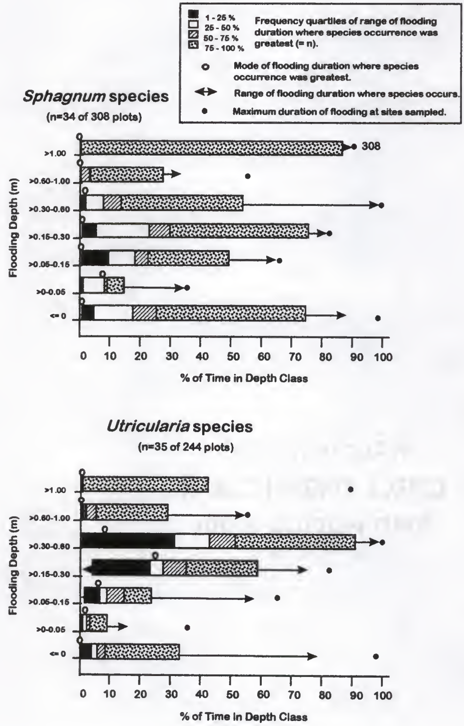


Figure 6-7--continued.

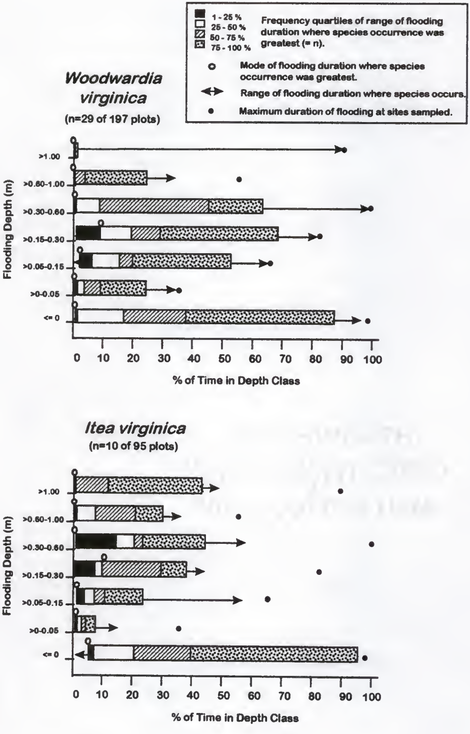


Figure 6-7--continued.

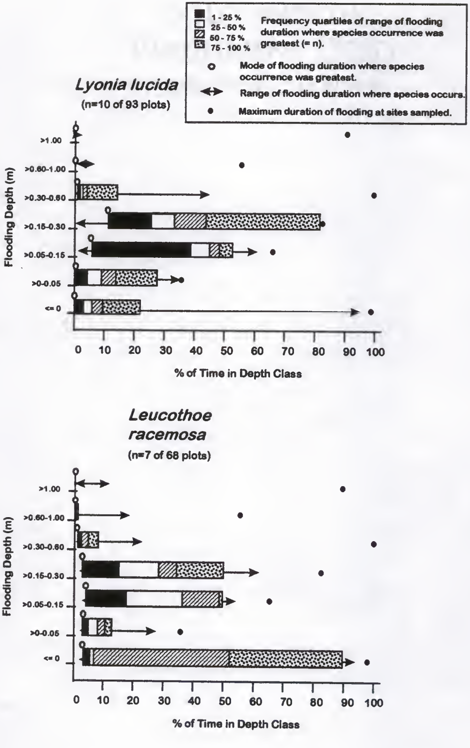


Figure 6-7--continued.

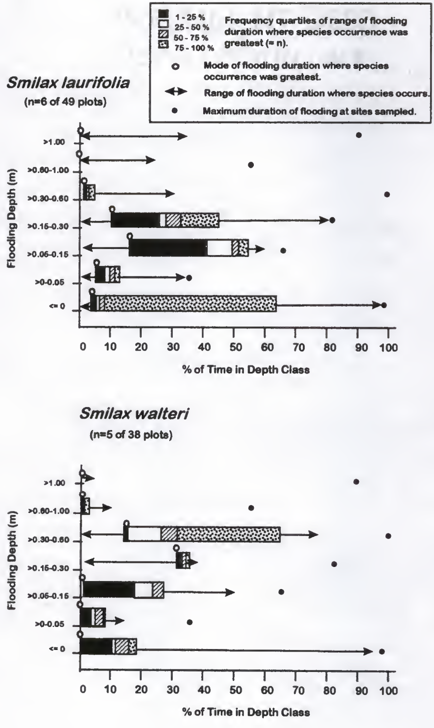
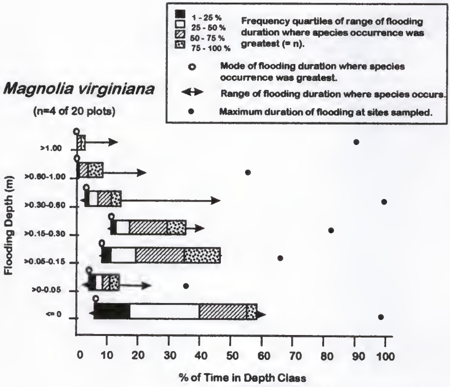


Figure 6-7--continued.



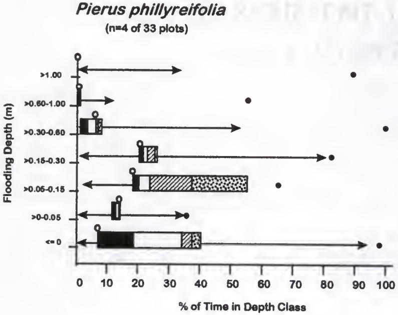
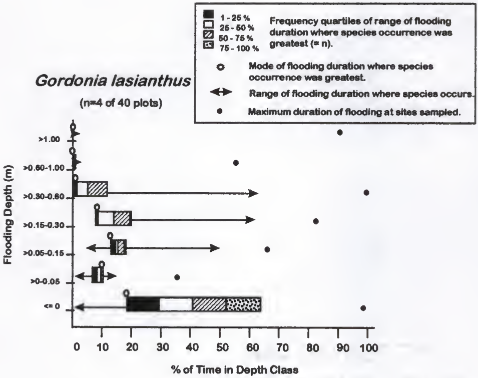


Figure 6-7--continued.



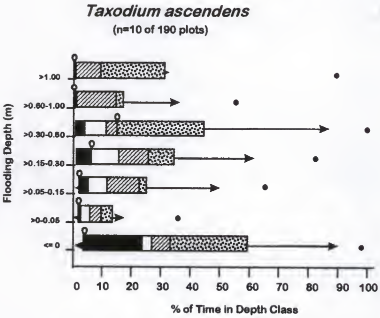
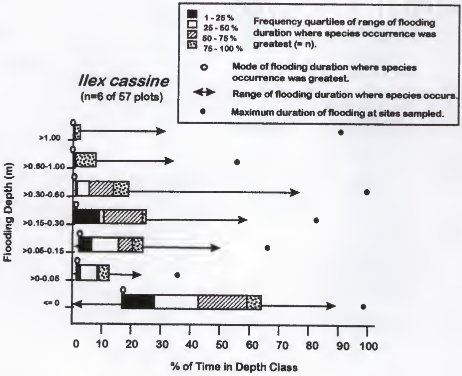


Figure 6-7--continued.



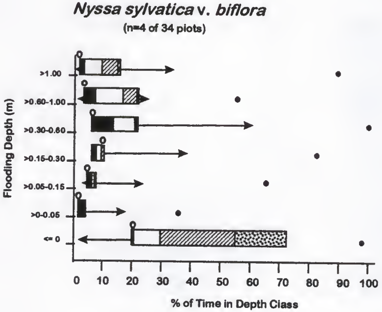


Figure 6-7--continued.

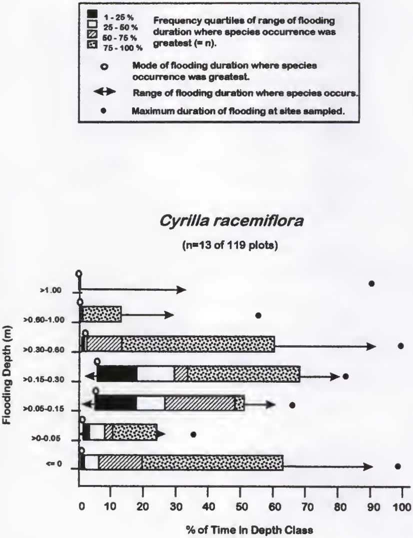
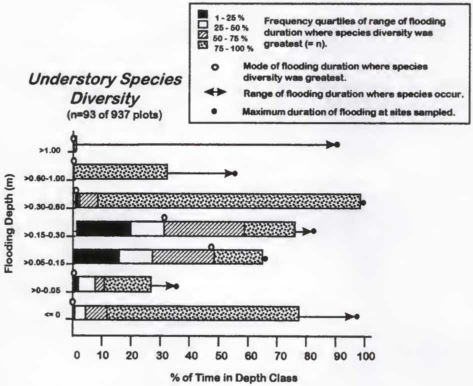


Figure 6-7--continued.



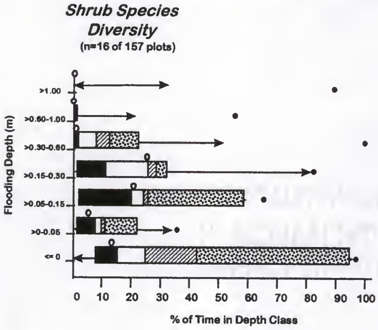


Figure 6-7--continued.

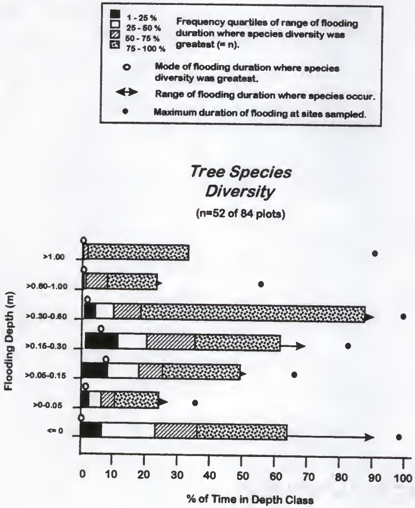


Figure 6-7--continued.

associations could be identified by examining similar species' distributions relative to flooding extent and duration, and light availability.

Sufficient data were available to calculate regression models for 26 species. Initial efforts focused on modeling data from all samples (n=942) for all 26 species, regardless of species presence. When considering all sample sites, most herbaceous species were negatively associated with all the modeled hydrologic variables, suggesting that their infrequent occurrence throughout the swamp resulted in a significant departure from zero whenever they did occur (Table 6-6). Therefore, these species were not further examined with the "all sample" models, but were further analyzed with the "species present" models, which would elucidate the species-environment relationships where the species occurred. Abundances of several shrub and tree species were significantly related to selected hydrologic parameters in the "all sample" models, and, unlike the herbaceous species, single depth classes were responsible for this relationship when all samples were considered. None of these species were significantly related to inundation duration in deep water (depth > 0.30 m). Trees species were generally associated with no inundation, whereas shrub species were inundated to shallow depths (Table 6-6). Light availability was not significantly related to occurrence for most shrub species, although a few were in greater abundance where light availability was low; most likely this low light availability was a function of the shrubs themselves, which generally were between 1-2 m in height. For those species significantly associated with shallow water depths (0-0.30 m), species' densities were most often correlated with duration of flooding to 0.05-0.15 m (Table 6-7). Tree and shrub diversities were greatest with inundation depth of

Table 6-6. Significant parameters in the species-environment multiple regression models using all herbaceous and woody sample data (logit-transformed) regardless of species presence.

Species	DC1[a]	DC2	DC3	DC1 x DC2	DC1 x DC3	DC2 x DC3	Low Level Light	High Level Light	Over-story Cover	Tran-sect	DC3 x Over-story	Over-story x Tran-sect	DC1 X Low Level Light	DC2 x Low Level Light	DC3 x Low Level Light	Low Level Light x Tran-sect	DC1 x High Level Light	DC3 x High Level Light	R_c^2	P > F	n
Carex walteriana	+++[b]	+++	+++	+	+++	+++	+++	+++		+++			+++						0.21	0.0001	942
Nymphaea odorata	---	---	---		---	---	+++		---	---		+++							0.44	0.0001	942
Xyris spp.	---	---	---	---	---	---	+++		--			+++							0.34	0.0001	942
Utricularia spp.	---	---	---		---	+++	+++												0.22	0.0001	942
Eriocaulon lineare	---	---	---	---		---	++												0.21	0.0001	942
Rhynchos-pora inundata	---	---	---	--			+++									-			0.04	0.0001	942
Eleocharis baldwinii/ vivipara	---	---	---		+++	---		+	--									---	0.18	0.0001	942
Panicum hemitomon	---	---	---					++	-		+++								0.06	0.0001	942
Lacnanthes caroliniana	---	---	---		++	---	--	+++										---	0.13	0.0001	942
Nuphar luteum	---	---	---	--	+++	---	--		---										0.14	0.0001	942
Woodwardia virginica	---	---	---		--	---	---			---						+++			0.21	0.0001	942
Peltandra virginica	---	---	---	+/	---		---			+							++		0.15	0.0001	942
Sphagnum spp.	---	---	---		--	---											+++		0.25	0.0001	942

Table 6-6--continued.

Species	DC1 a	DC2	DC3	DC1 x DC2	DC1 x DC3	DC2 x DC3	Low Level Light	High Level Light	Over-story Cover	Tran-sect	DC3 x Over-story	Over-story x Tran-sect	DC1 X Low Level Light	DC2 x Low Level Light	DC3 x Low Level Light	Low Level Light x Tran-sect	DC1 x High Level Light	DC3 x High Level Light	R_c^2	P > F	n
Itea virginica	---	---	---							++				--					0.04	0.0001	942
Leucothoe racemosa	++	+++				---		---	-									+++	0.13	0.0001	489
Smilax walteri	+++				--			-		+++									0.05	0.0001	489
Ilex cassine	+++																		0.05	0.0001	166
Nyssa sylvatica v. biflora	+			--	+++														0.20	0.0001	166
Acer rubrum	++			--	+/														0.11	0.0001	166
Cyrilla racemiflora		+++				---	--			++					++				0.14	0.0001	489
Lyonia lucida		+++		---		---	+++			--				---					0.34	0.0001	489
Smilax laurifolia		+++		-/		--			++			-							0.06	0.0001	489
Pierus phillyret-folia				+++			--			+++									0.05	0.0001	489
Taxodium ascendens				+		-/				++									0.09	0.0001	166
Magnolia virginiana				+		--				++									0.09	0.0001	166
Gordonia lasianthus				+++						--									0.14	0.0001	166
Understory Species Diversity	+++	+++	+++	---	---	---				---							+++		0.36	0.0001	944

Table 6-6--continued.

Species	DC1 [a]	DC2	DC3	DC1 x DC2	DC1 x DC3	DC2 x DC3	Low Level Light	High Level Light	Over-story Cover	Tran-sect	DC3 x Over-story	Over-story x Tran-sect	DC1 X Low Level Light	DC2 x Low Level Light	DC3 x Low Level Light	Low Level Light x Tran-sect	DC1 x High Level Light	DC3 x High Level Light	R_c^2	P > F	n
Shrub Species Diversity	++	+++			- -	- - -			+++	+++									0.33	0.0001	489
Tree Species Diversity		+++	+		++	- - -				+									0.16	0.0001	166

[a] Depth Classes (DC) are:

no inundation	DC1	water depth ≤ 0 m
shallow water	DC2	$0 <$ water depth ≤ 0.30 m
deep water	DC3	water depth > 0.30 m

[b] Cell entries represent slope and α-levels for tests of significance as follows:

+++, - - -	$P \leq 0.001$
++, - -	$P \leq 0.01$
+, -	$P \leq 0.05$
+/, -/	$P \leq 0.10$

[c] R_m^2, the multiple regression coefficient, has been modified for absence of the y-intercept in the model.

Table 6-7. Significant parameters in the species-environment multiple regression models using all herbaceous and woody species sample data regardless of species presence, when inundation depths are shallow ($0 < \text{depth} \leq 0.30$ m).

Species	DC3[a]	DC4	DC2x DC3	DC2 x DC4	DC3 x DC4	Low Level Light	High Level Light	Overstory Cover	Transect	Overstory x Transect	DC3 x Low Level Light	R_c^2	P > F	n
Leucothoe racemosa	+++[b]						- - -					0.11	0.0001	489
Cyrilla racemiflora	+++										- - -	0.13	0.0001	489
Lyonia lucida	+++			- - -		+++	- -		- - -		- - -	0.34	0.0001	489
Smilax laurifolia			+++					+		- -		0.07	0.0001	489
Understory Species Diversity	+++	+++		- - -	-		+++	+++	- -			0.30	0.0001	942
Shrub Species Diversity	+++			- -	- - -	- -		+++				0.31	0.0001	489
Tree Species Diversity	+++	+			- -							0.07	0.0001	166

[a] Shallow water depth Classes (DC) are: DC2 $0 \leq \text{water depth} \leq 0.05$ m
DC3 $0.05 \text{ m} < \text{water depth} \leq 0.15$ m
DC4 $0.15 < \text{water depth} \leq 0.30$ m

Table 6-7--continued.

[b] Cell entries represent slope and α-levels for tests of significance as follows:

+++, - - -	$P \leq 0.001$	+, -	$P \leq 0.05$
++, - -	$P \leq 0.01$	+/, -/	$P \leq 0.10$

[c] R_m^2, the multiple regression coefficient, has been modified for absence of the y-intercept in the model.

0.05-0.15 m, and shrub diversity was greatest when overstory cover was high; understory diversity was high regardless of inundation conditions or light availability (Table 6-6). The *transect* variable was significantly associated with several species, suggesting that species were not uniformly distributed throughout the areas (Table 6-7).

Significant model parameters that describe environments where selected species were present are listed in Table 6-8 (flooding conditions are no inundation, shallow water, or deep water) and Table 6-9 (division of shallow water depth as 0-0.05 m, 0.05-0.15 m, and 0.15-0.30 m). Woody species were usually associated with shallower conditions than herbaceous species, and light levels and transect were significant parameters for less than half of the sampled species (Table 6-8). Species associations are grouped by average and standard deviation of water depths in Table 6-10.

Inundation conditions and durations described in Table 6-7 by the species' multiple regression models are represented in 3-dimensional plots in Figure 6-8. These plots illustrate the observed data and regression model-predicted species abundances with inundation depth and duration. Light availability and transect parameters are included in the models where appropriate, but are not diagramed in these plots. Although the figure base is a square to facilitate viewing, the modeled surface is confined to the lower right half creating a surface triangle. Two of the three modeled inundation parameters are illustrated on the axes (% time with no inundation and % time in shallow water), and the third parameter (% time in deep water) is the difference of these parameters from 100% (100% -% time no inundation - % time in shallow water = % time in deep water). For example, hurrahbush (*Lyonia lucida*) was found in greatest

Table 6-8. Significant parameters in the species-environment multiple regression models using understory, shrub, and tree sample data where species are present.

Species	DC1[a]	DC2	DC3	DC1 x DC2	DC1 x DC3	DC2 x DC3	Low Level Light	High Level Light	Over-story Cover	Tran-sect	DC1 x Over-story	DC3 x Over-story	Over-story x Tran-sect	DC3 x Low Level Light	Low Level Light x Tran-sect	DC2 x High Level Light	R_c^2	P > F	n
Carex walteriana	+++[b]	+++			+++	+++	- - -	+	- - -			+++					0.16	0.0001	437
Leucothoe racemosa	+	+++					+	-/									0.11	0.0001	68
Lyonia lucida	+	+++		-/			- - -			- -					-		0.31	0.0001	93
Gordonia lasianthus	+	+/		-/	+					-							0.34	0.0009	33
Peltandra virginica	+	++			+++		-	++		- - -							0.09	0.0001	356
Xyris spp.		+++				- - -											0.36	0.0001	248
Lacnanthes caroliniana	+/	++	+++	-/	++	- - -											0.36	0.0001	266
Woodwardia virginica	+++	+++	+++			-	-		- -					- - -			0.23	0.0001	197
Acer rubrum	+	-	+	+	+	-				-							0.99	0.0271	8
Magnolia virginiana	++																0.12	0.0145	20
Itea virginica	+				+++												0.10	0.0001	95
Sphagnum spp.		+++	+++	+++	-/	- -											0.09	0.0001	308
Nuphar luteum		+	+++		-/	- -						- -					0.38	0.0001	68

Table 6-8--continued.

Species	DC1[a]	DC2	DC3	DC1 x DC2	DC1 x DC3	DC2 x DC3	Low Level Light	High Level Light	Over-story Cover	Tran-sect	DC1 x Over-story	DC3 x Over-story	Over-story x Tran-sect	DC3 x Low Level Light	Low Level Light x Tran-sect	DC2 x High Level Light	R_c^2	P > F	n
Cyrilla racemiflora		+++	++			-/											0.07	0.0001	119
Eriocaulon lineare		+++															0.07	0.0001	44
Smilax walteri		+++			-/	++				+++							0.16	0.0001	38
Nymphaea odorata			+++				+++										0.21	0.0001	361
Eleocharis baldwinii/ vivipara	+/		+				+/							-			0.07	0.0001	157
Panicum hemitomon				+	+++												0.07	0.0001	228
Taxodium ascendens				+++													0.06	0.0001	93
Nyssa sylvatica v. *biflora*					++												0.08	0.0014	34
Rhynchospora indundata						- -	+++										0.27	0.0003	35
Utricularia spp.							+++		- -	+++					- - -		0.50	0.0001	244
Ilex cassine	+++																0.06	0.0002	57
Pierus phillyreifolia							+++										0.11	0.0004	33
Smilax laurifolia									+	+			+				0.01	0.0065	49
Understory Species Diversity	+++	+++	+++	- - -	- - -	- - -		+	+	- - -	- - -					+++	0.37	0.0001	937

Table 6-8--continued.

Species	DC1[a]	DC2	DC3	DC1 x DC2	DC1 x DC3	DC2 x DC3	Low Level Light	High Level Light	Over-story Cover	Tran-sect	DC1 x Over-story	DC3 x Over-story	Over-story x Tran-sect	DC3 x Low Level Light	Low Level Light x Tran-sect	DC2 x High Level Light	R_c^2	P > F	n
Shrub Species Diversity	+++	+++							+/	+++							0.15	0.0001	157
Tree Species Diversity		+++	++		++	- - -											0.10	0.0001	165

[a] Depth Classes (DC) are:

	no inundation	DC1	water depth ≤ 0 m
	shallow water	DC2	$0 <$ water depth ≤ 0.30 m
	deep water	DC3	water depth > 0.30 m

[b] Cell entries represent slope and α-levels for tests of significance as follows:

+++, - - -	$P \leq 0.001$
++, - -	$P \leq 0.01$
+, -	$P \leq 0.05$
+/, -/	$P \leq 0.10$

[c] R_m^2, the multiple regression coefficient, has been modified for absence of the y-intercept in the model.

Table 6-9. Significant parameters in the species-environment multiple regression models using herbaceous and woody species sample data where species are present and inundation depths are shallow (0 < depth ≤ 0.30 m).

Species	DC2[a]	DC3	DC4	DC2 x DC3	DC2 x DC4	DC3 x DC4	Low Level Light	High Level Light	Over-story Cover	Tran-sect	Over-story x Tran-sect	DC2 x Low Level Light	DC3 x Low Level Light	DC4 x Low Level Light	Low Level Light x Tran-sect	DC2 x High Level Light	DC4 x High Level Light	High Level Light x Tran-sect	R_m^2	P > F	n
Carex walteriana		+++[b]	+++	- - -	+++	- - -	-		- - -		++								0.09	0.0001	437
Leucothoe racemasa							+++		+++										0.05	0.0001	68
Lyonia lucida		+++	+				- -		-/	++			+						0.10	0.0001	68
Gordonia lasianthus	+																		0.09	0.0124	33
Peltandra virginica			+++																0.08	0.0001	356
Smilax laurifolia		+++																	0.03	0.0001	49
Xyris spp.		+++																	0.12	0.0001	248
Lacnanthes caraliniana			-/		- -			+++	+++										0.03	0.0001	266
Woodwardia virginica			+							++									0.15	0.0001	197
Sphagnum spp.			+++						+++	+		+++							0.09	0.0001	308
Nuphar luteum	-						-		-/	+++			+						0.10	0.0001	68
Cyrilla racemiflora		+++	++																0.01	0.0001	119

Table 6-9--continued.

Species	DC2[a]	DC3	DC4	DC2 x DC3	DC2 x DC4	DC3 x DC4	Low Level Light	High Level Light	Over-story Cover	Tran-sect	Over-story x Tran-sect	DC2 x Low Level Light	DC3 x Low Level Light	DC4 x Low Level Light	Low Level Light x Tran-sect	DC2 x High Level Light	DC4 x High Level Light	High Level Light x Tran-sect	R_m^2	P > F	n
Eriocaulon lineare		+++				-									-				0.35	0.0001	44
Smilax walteri			+							++									0.07	0.0001	38
Understory Species Diversity		+++	+++		- - -			+++	+++	- - -							- - -		0.30	0.0001	938
Shrub Species Diversity		+++	+/			- -	++		+++	+++				-/					0.12	0.0001	157
Tree Species Diversity		+++	+			- -													0.07	0.0001	167

[a] Shallow water depth Classes (DC) are:
DC2 0 m < water depth ≤ 0.05 m
DC3 0.05 m < water depth ≤ 0.15 m
DC4 0.15 m < water depth ≤ 0.30 m

[b] Cell entries represent slope and α-levels for tests of significance as follows:
+++, - - - P ≤ 0.001
++, - - P ≤ 0.01
+, - P ≤ 0.05
+/, -/ P ≤ 0.10

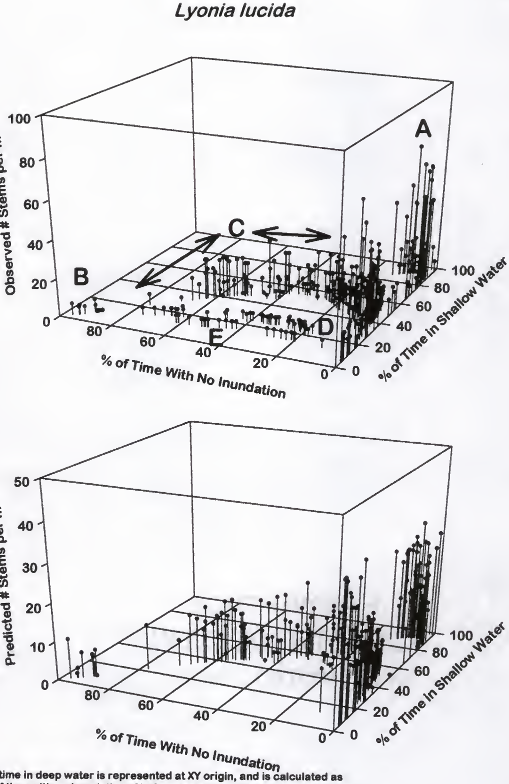
[c] R_m^2, the multiple regression coefficient, has been modified for absence of the y-intercept in the model.

Table 6-10. Associations of vegetation species based on average and standard deviation of daily water depths measured or estimated at transect sample sites during 1962-1995. Values in column headings are the ranges of average water depths ± the ranges of standard deviations.

Deep, Variable (0.20-0.26± 0.21-0.28m)	Deep, Moderate Variability (0.21-0.29± 0.12-0.15m)	Deep, Constant (0.23-0.30± 0.06-0.10m)	Moderate Depth, Variable	Moderate Depth, Moderate Variability (0.15-0.16± 0.14-0.20m)	Moderate Depth, Constant (0.12-0.15± 0.05-0.10m)	Shallow, Variable (0.09-0.10± 0.21-0.33m)	Shallow, Moderate Variability (0.06-0.10± 0.11-0.19m)	Shallow, Constant (0.08±0.10m)
Transition:								
Aquatic Prairie or Lake	and Creek and River Channels	to Deep Herbaceous Prairie		to Moderately Deep Herbaceous Prairie		to Creek and River Floodplains		to Shallow Herbaceous Prairie
Nuphar luteum	*Nymphaea odorata*	*Eleocharis robbinsii*		*Pinus* spp	*Saggitaria graminea*	*Ilex myrtifolia*	*Acer rubrum*	*Gordonia lasianthus*
Cephalanthus occidentalis	*Utricularia* spp.	*Brasenia schreberi*		*Peltandra virginica*	*Bidens mitis*	*Nyssa ogeechee*	*Persea palustris*	
Nyssa sylvatica v. *biflora*	*Clethra alnifolia*	*Ludwigia alata*		*Eleocharis baldwinii/ vivipara*	*Lycopodium spp.*		*Woodwardia virginica*	
Fraxinus caroliniana	*Taxodium ascendens*	*Andropogon virginiana*			*Triadenum virginicum*		*Smilax walteri*	

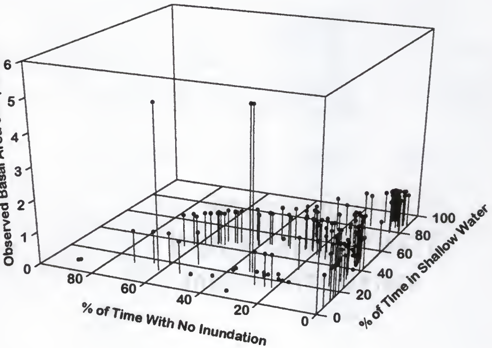
Table 6-10--continued.

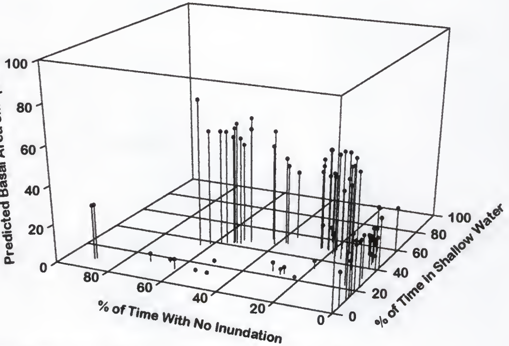
Deep, Variable (0.20-0.26± 0.21-0.28m)	Deep, Moderate Variability (0.21-0.29± 0.12-0.15m)	Deep, Constant (0.23-0.30± 0.06-0.10m)	Moderate Depth, Variable	Moderate Depth, Moderate Variability (0.15-0.16± 0.14-0.20m)	Moderate Depth, Constant (0.12-0.15± 0.05-0.10m)	Shallow, Variable (0.09-0.10± 0.21-0.33m)	Shallow, Moderate Variability (0.06-0.10± 0.11-0.19m)	Shallow, Constant (0.08±0.10m)
Sphagnum spp.	*Orontium aquaticum*	*Eriocaulon lineare*			*Sarracenia flava*		*Smilax laurifolia*	
Itea virginica	*Carex walteriana*	*Iris virginiana*			*Sarracenia psitticenia*		*Cyrilla racemiflora*	
Dulichium arendinaceum	*Xyris* spp.	*Drosera intermedia*					*Pierus phillyreifolia*	
	Rhynchospora inundata						*Lyonia lucida*	
	Panicum hemitomon						*Leucothoe racemosa*	
	Decodon verticillatus						*Ilex cassine*	
							Magnolia virginiana	
							Lacnanthes caroliniana	
							Rhynchospora chalerocephala /wrightiana	



Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

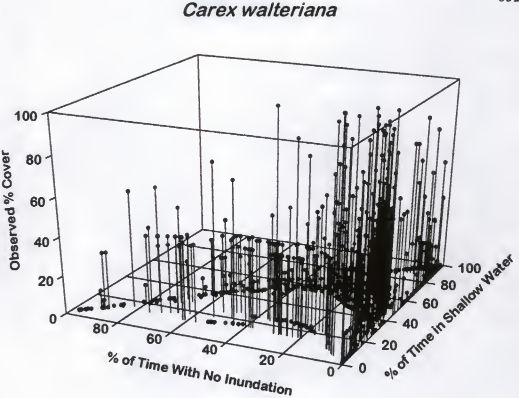
Figure 6-8. Distribution of sample points in observed and model-predicted relationships between species abundance (1993-1994) and inundation depth and duration (1962-1995).

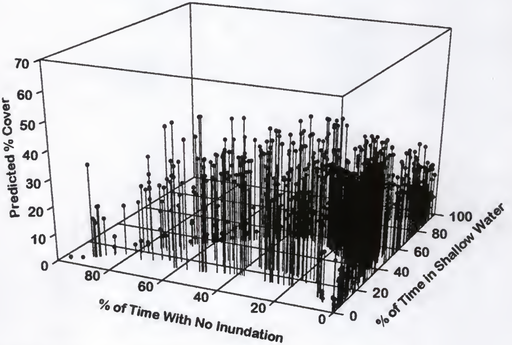




Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

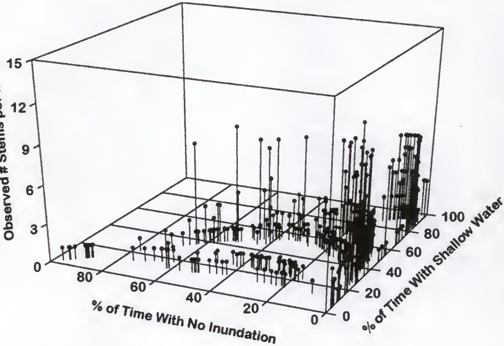


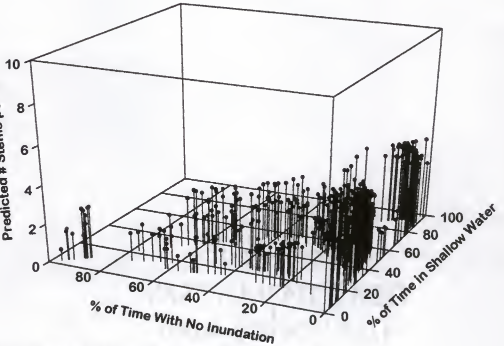


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

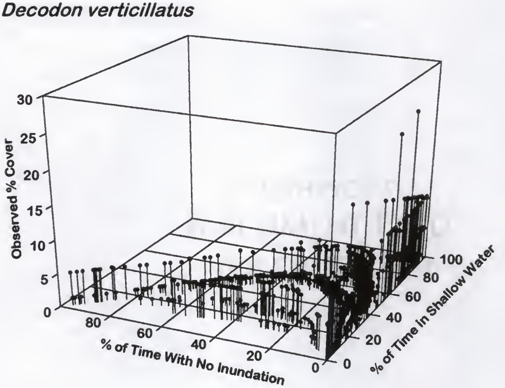
Cyrilla racemiflora

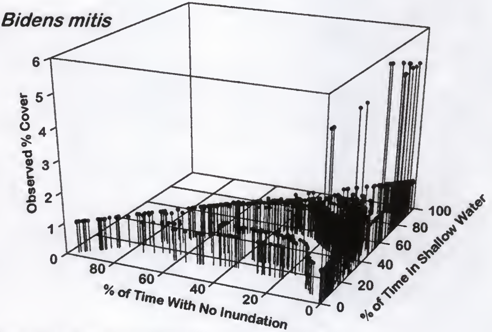




Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

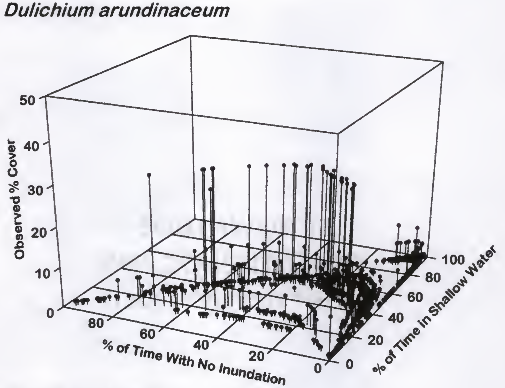
Figure 6-8--continued.

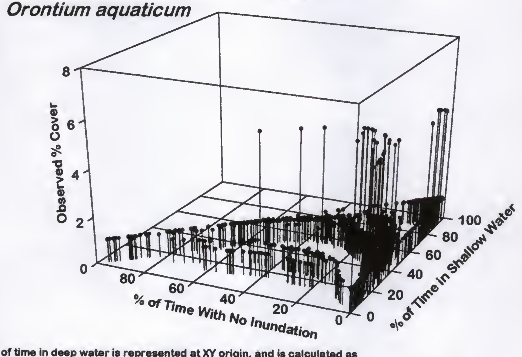




Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

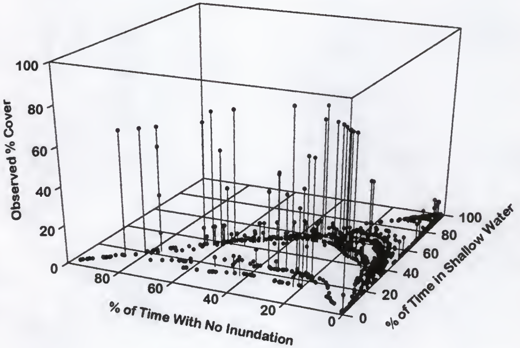


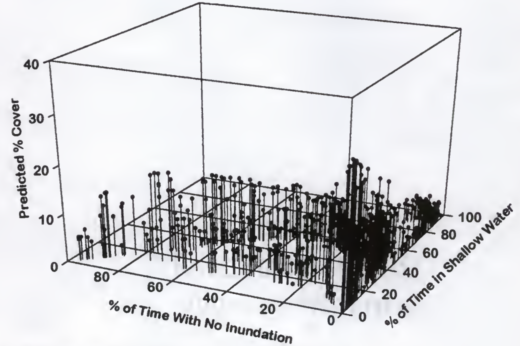


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

Eleocharis baldwinii/vivipara

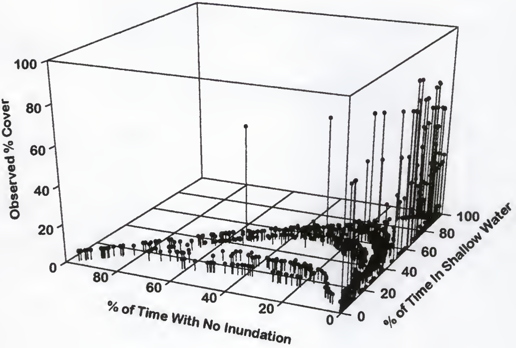


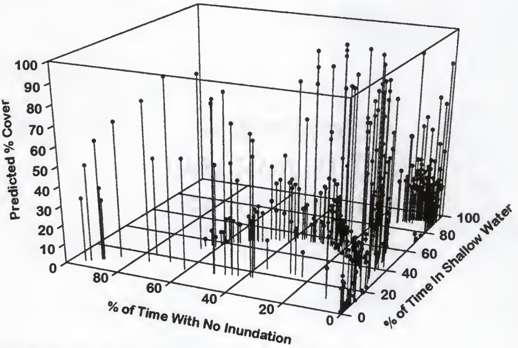


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

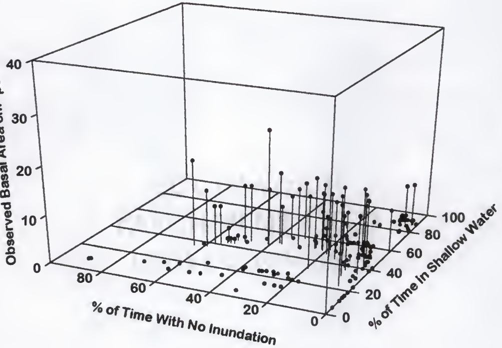
Eriocaulon lineare

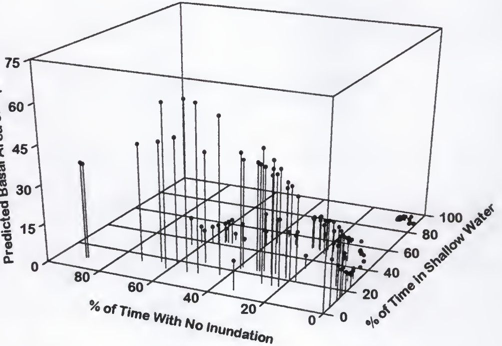




Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

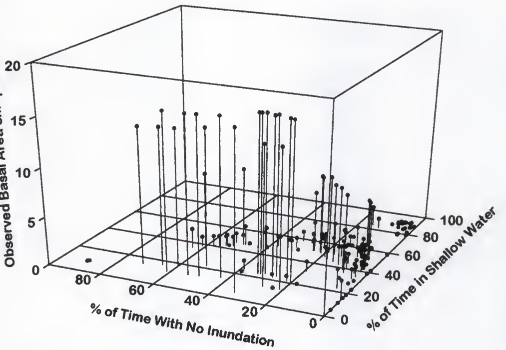


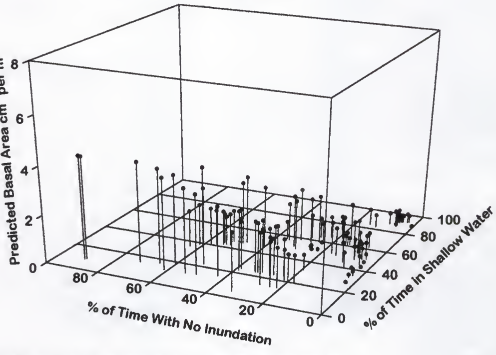


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

Ilex cassine

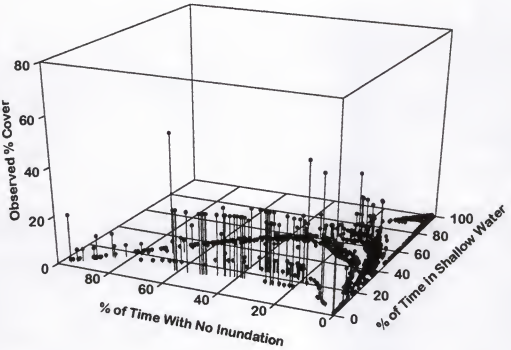


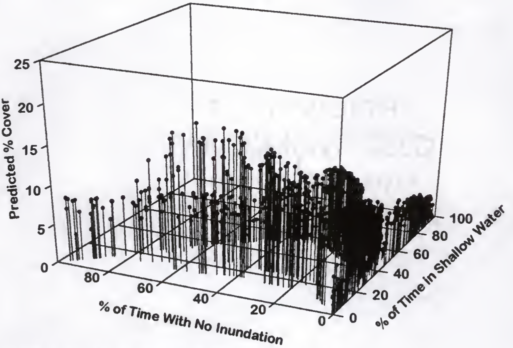


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

Itea virginica

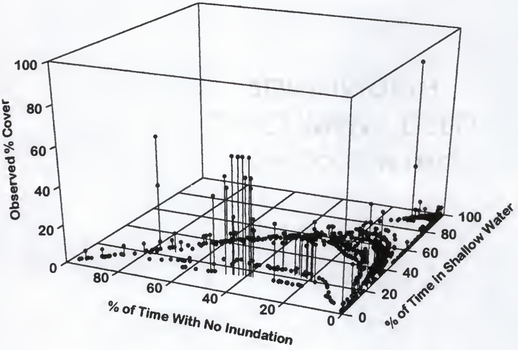


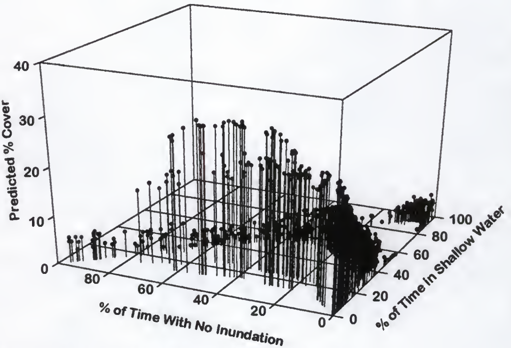


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

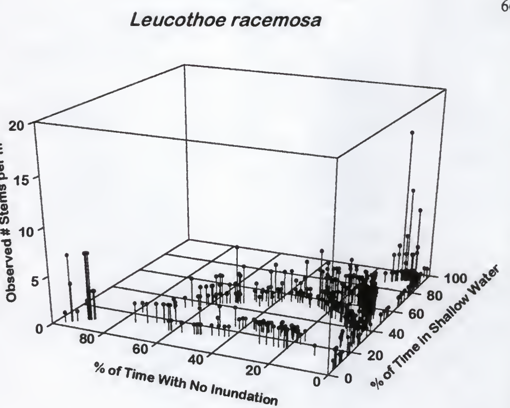
Lacnanthes caroliniana

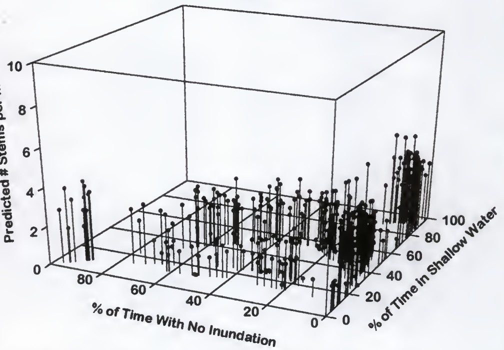




Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

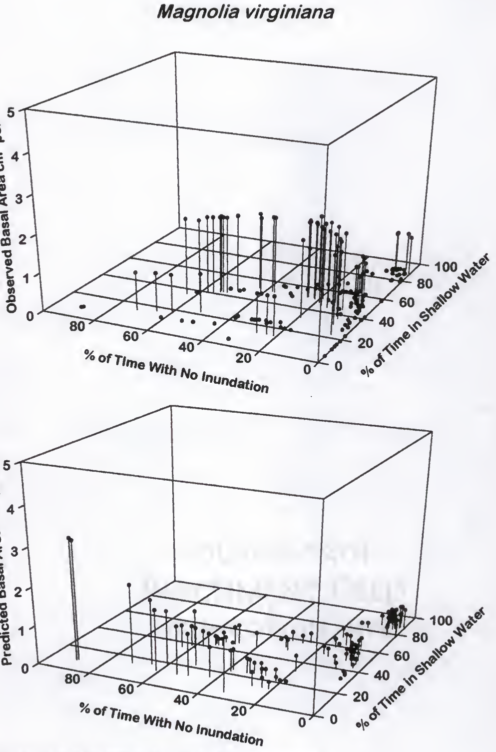
Figure 6-8--continued.





Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.



Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

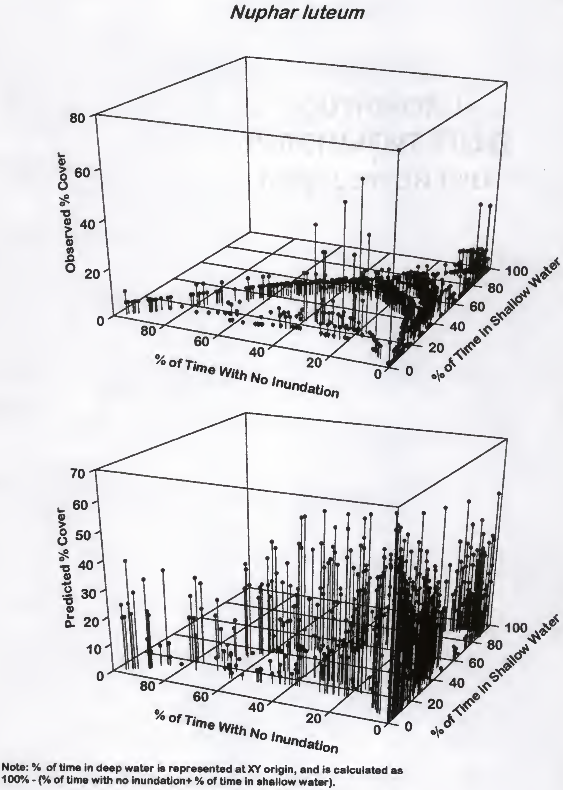
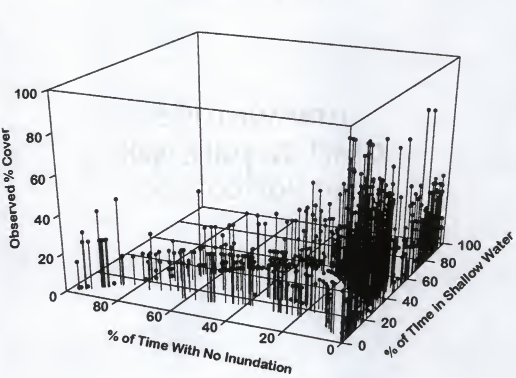
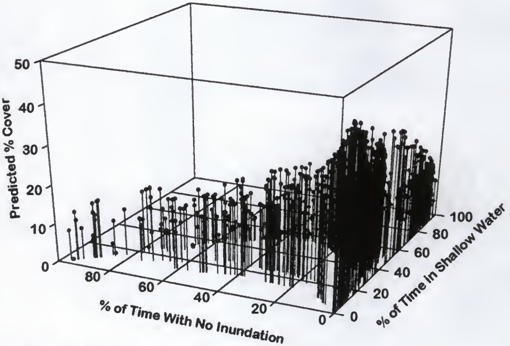


Figure 6-8--continued.

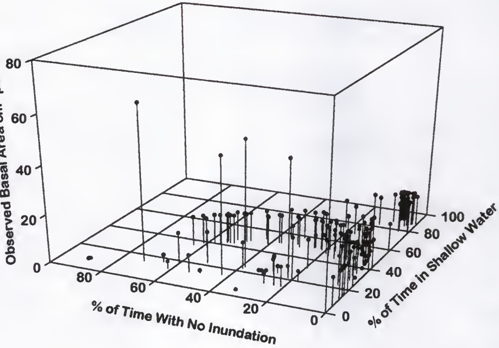


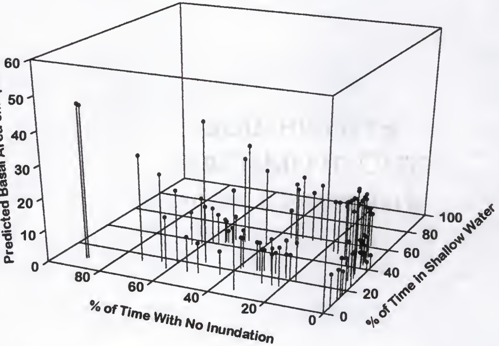


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

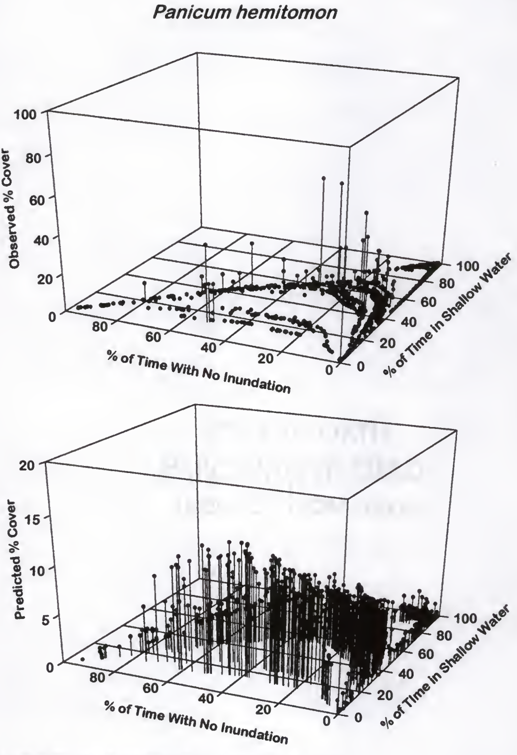
Nyssa sylvatica v. *biflora*





Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

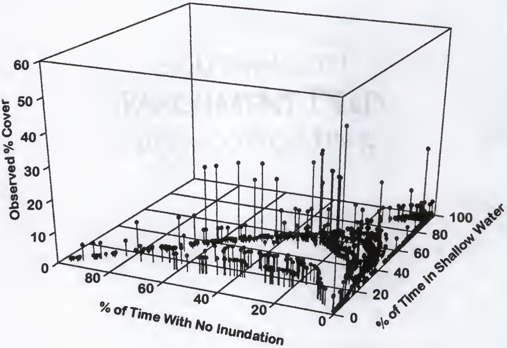
Figure 6-8--continued.

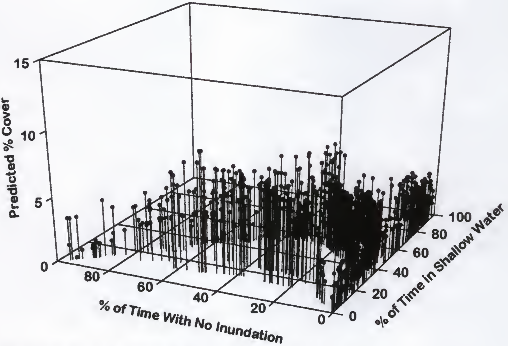


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

Peltandra virginica

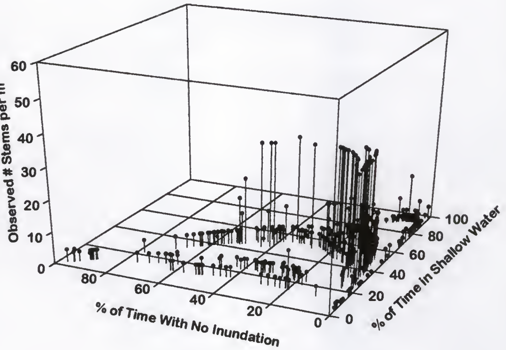


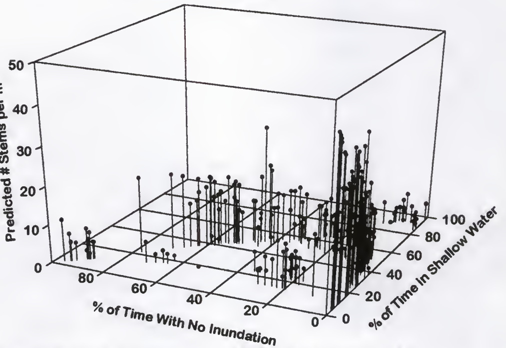


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

Pierus phillyreifolia

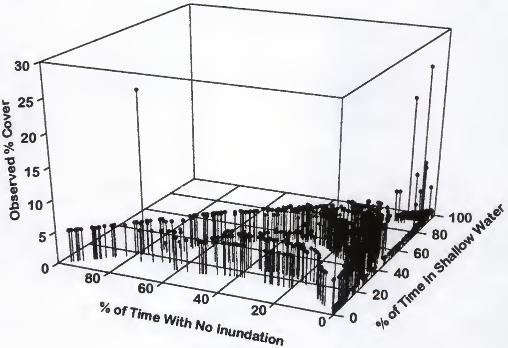


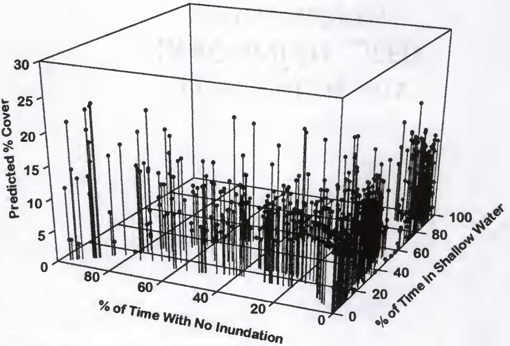


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

Rhynchospora inundata

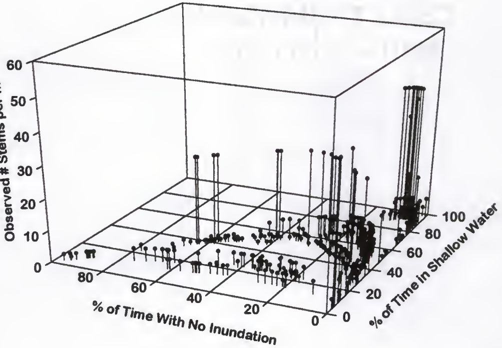


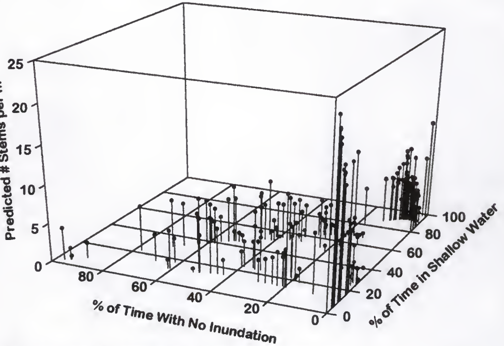


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

Smilax laurifolia

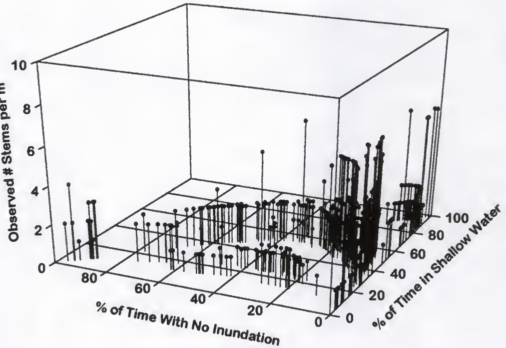


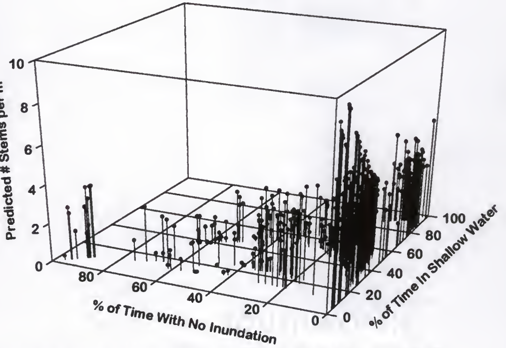


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

Smilax walteri

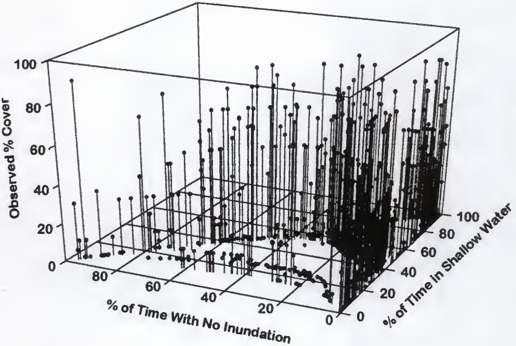


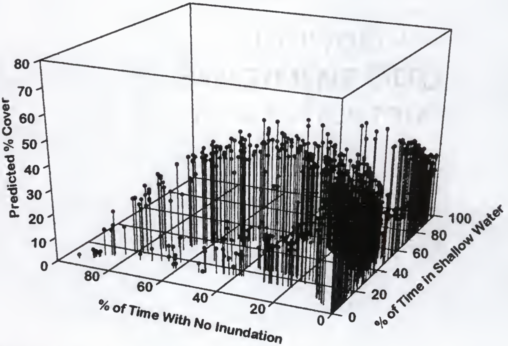


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

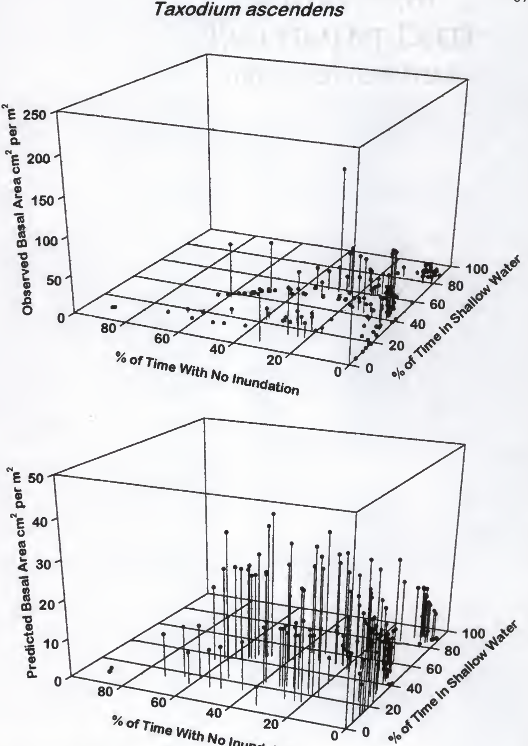
Sphagnum species





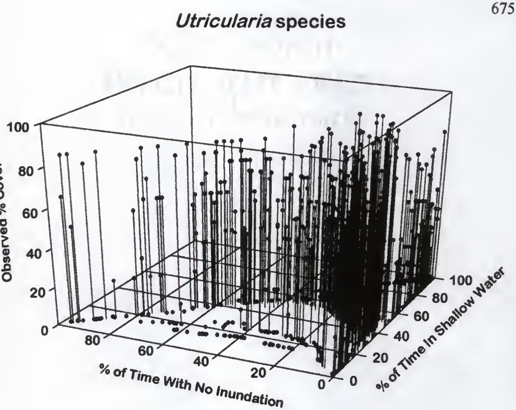
Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

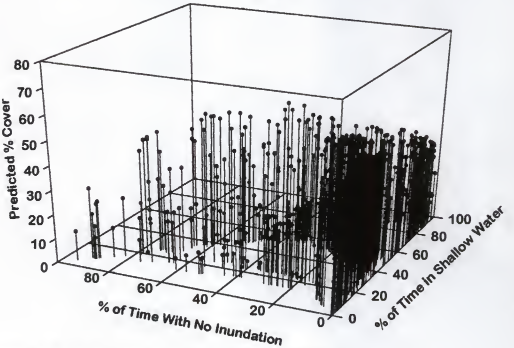
Figure 6-8--continued.



Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

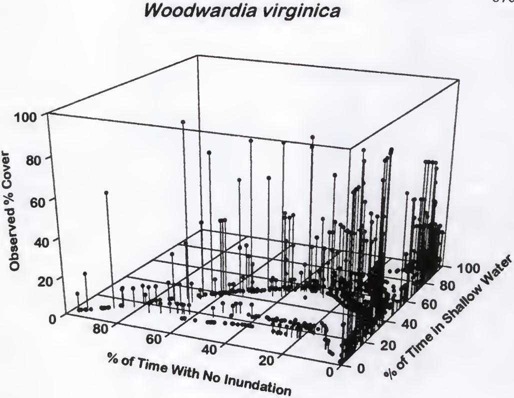
Figure 6-8--continued.

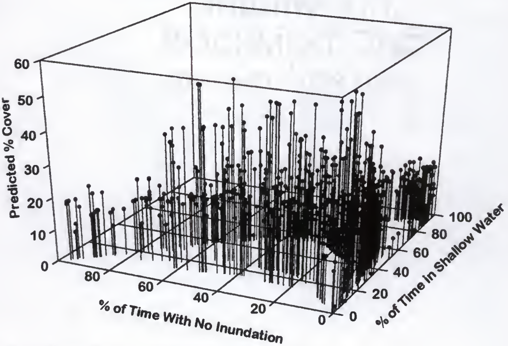




Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

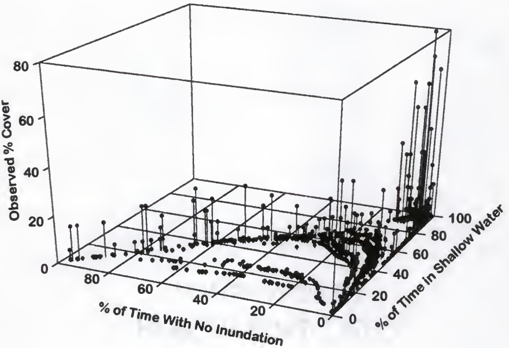


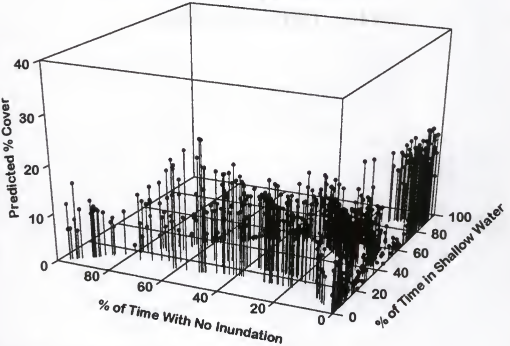


Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

Xyris species





Note: % of time in deep water is represented at XY origin, and is calculated as 100% - (% of time with no inundation+ % of time in shallow water).

Figure 6-8--continued.

abundance where water depths were shallow 80-100% of the time, with no inundation < 20% of the time, and therefore by difference, in deep water < 20 % of the time. Species abundance at a site under this hydrologic condition is indicated by the height of the point and drop-line above the triangle base. This relationship is labeled **A** in the top plot of *Lyonia lucida* in Figure 6-8. At **B** in this plot, no inundation occurs 80-100% of the time, shallow water depths occur < 20% of the time, deep water depths occur < 20% of the time, and abundance of hurrahbush is low (< 10 stems/m^2). Points in the region marked **C** are shallow or without inundation, but never deeply inundated, and stem density gradually increases with increasing duration of shallow flooding. Points in the region marked **D** are always deeply flooded, and stems are absent or in low densities. Points in the region marked **E** are usually without inundation or in deep water, and in shallow water < 20% of the time; stem densities are < 10 stems/m^2. The bottom plot illustrates the model-predicted *Lyonia lucida* abundance. Comparison of the observed (top plot) and predicted (bottom plot) abundances illustrates the model fit to the data (R_m^2). Plot curvatures indicate water depth class interactions; greater curvature occurs with more significant interactions among inundation conditions, and also indicates water depth variability. Examination of the plots reveals groups of species with similar point distributions and abundance-hydrologic environment trends. These groups are listed in Table 6-11.

Table 6-11. Associations of vegetation species based similar 3-dimensional plots of modeled species occurrence and daily depth-inundation duration relationships at transect sample sites during 1962-1995.

Group	Species	Significant Model Parameters[a, b]
1	chain fern, Walter's sedge, arum	DC1, DC2, DC3, DC1xDC3, DC2xDC3, low level light, high level light, overstory cover
2	beakrush, hat pins, yellow-eyed grass, water willow, tickseed	DC2, DC2xDC3, low level light
3	swamp blackgum, dahoon holly, sweet bay	DC1, DC1xDC3
4	*Sphagnum* spp., pond cypress, 3-square, golden club, spikerush, spatterdock	DC1, DC2, DC3, DC1xDC2, DC1xDC3, DC2xDC3, low level light
5	loblolly bay, red maple	DC1, DC2, DC3, DC1xDC2, DC1xDC3, DC2xDC3
6	Virginia willow, red root, maidencane	DC1, DC2, DC3, DC1xDC2, DC1xDC3, DC2xDC3
7	bladderworts	low level light, overstory cover
8	water lily	DC3, low level light
9	hurrahbush, climbing fetterbush	DC1, DC2, DC1xDC2, low level light
10	Walter's greenbriar, bamboo greenbriar	DC2, DC1xDC3, DC2xDC3,overstory cover
11	titi, fetterbush	DC1, DC2, DC3, DC2xDC3, low level light, high level light

[a] Significant model parameters are listed for all species in group, but all may not be significant for all species in group. See Table 6-8 for significant parameter for specific species.

[b] Average daily water depths are represented in depth classes as:

No inundation DC1 water depth ≤ 0 m

Table 6-11--continued.

Shallow water	DC2	0 m < water depth $\leq$ 0.05 m
Shallow water	DC3	0.05 m < water $\leq$ 0.15 m
Shallow water	DC4	0.15 m < water depth $\leq$ 0.30 m
Deep water	DC5	0.30 m < water depth $\leq$ 0.60 m
Deep water	DC6	0.60 m < water depth $\leq$ 1.00 m
Deep water	DC7	1.00 m > water depth

Species' Environments and Modeled Hydrologic Changes

Hydrologic changes predicted with sill removal were compared with significant parameters of the species-environment multiple regression models to suggest vegetation changes possible with sill removal. Affects of the sill on the swamp hydrologic environment are predicted primarily for the central and western swamp (Figure 3-9). In most of this area hydroperiods will be shortened under deeper conditions, and high water depths will decrease with sill removal. The region close to the sill will also experience more fluctuations in water depths, with longer periods of exposed peat. These hydrologic changes will be sufficient to permit slight changes in vegetation composition, based on the species-environment model results (Table 6-12). However, other factors such as seed dispersal, changes in disturbance regimes, and competitive interactions among invading and established species might modify the outcome of these changes that are predicted based on the hydrologic environments.

Discussion

Species Associations and the Hydrologic Environment

The vegetation of Okefenokee Swamp is a moving mosaic in a landscape that has resulted in part from periodic, unpredictable perturbations and competitive interactions among species (Hamilton 1984, 1982). Fire is the most frequent, extensive, and intensive disturbance occurring in the system, although small-scale storms and infrequent

Table 6-12. Predicted changes in biweekly water depth range (from depth classes) and variability by swamp region, predicted by the swamp hydrology model with sill removal (summarized from Figure 3-18).

Range of Most Frequent Average Biweekly Water Depths with Sill in Place	**Range of Most Frequent Average Biweekly Water Depths with Sill Removal**	**Affected Area of Swamp**
0.05 - 0.60 m	0 - 0.30 m	Chase Prairie
0.05 - 1.00 m	0.05 - 0.60 m	Craven's Hammock
0.15 - 1.00 m	0.05 - 0.60 m	Floyd's Prairie, Sapling Prairie, Sapp Prairie
0.15 - 1.00 m	0 - 0.30 m	Cypress Creek
0.15 - 1.00 m	0.15 - 0.60 m	Territory Prairie
0.30 - 1.00 m	0.30 - 0.60 m	Billy's Lake
0.30 - 1.00 m	0.15 - 1.00 m	Sill Gate Area
0.30 - 1.00 m	0.15 - 0.60 m	SCFSP
0.60 - 1.00 m	0.30 - 1.00 m	Suwannee River Narrows, Area Southwest of Sill
0.60 - 1.00+ m	0.30 - 1.00 m	Sweetwater Creek

hurricanes creating local damage due to high winds also occur (see Chapter 4). Vegetation communities occurring in the swamp today have been present throughout the swamp's development and occur throughout the accumulated peat (Cohen et al. 1984, Cohen 1974, 1973a, 1973b, Rich 1984a, 1984b, 1979), indicating that the disturbances occurring throughout the swamp's history have created conditions within the tolerances of the current suite of predominant species. There is a limited suite of species in the swamp seed bank that are tolerant of the swamp hydrologic environments. Variation in the landscape through time is an expression of these differential tolerances and species' plasticities in response to environmental change. Species composition and relative water levels (above and below ground) change through succession in a predictable pattern with peat accumulation, and are characteristic to a degree for each successional stage (Deuver 1982, 1979). Replacement of species results as conditions gradually become unsuitable for those present, but disturbances, primarily from fire, eventually occur that recreate the environments more suitable for early succession species tolerant of longer and deeper inundation.

Although fire history results in spatial variability of vegetation communities, the swamp hydrologic environment is also spatially and temporally variable; this variability and subtle differences in hydroperiod and inundation depths are reflected in the species composition, associations, and distributions. Pesnell and Brown (1977) found hydroperiod to be the primary factor determining plant distributions in Lake Okeechobee, FL, and Richardson et al. (1995) found that long-term hydroperiod variables (mean monthly water depth, variance, and hydroperiod) accounted for more variation in and

higher correlation with vegetation cover in lake Okeechobee, FL, marshes than short-term hydroperiod variables. Deuver (1988, 1984) found that hydroperiod and fire are controlling factors of plant community composition and distribution in Corkscrew Swamp and Big Cypress Swamp, FL, and Gunderson (1994, 1992) found that the Everglades system is structured by hydrology, fire, and vegetation interacting at multiple temporal and spatial scales. . The Okefenokee Swamp contains areas of nearly constant shallow and deep water, as well as areas dramatically affected by seasonal variations in water depths and flooding durations due to precipitation and evaporation variability (see Chapters 2 and 3). Species associated with each of these environments are related to different hydrologic conditions and histories, and can be modeled and diagramed to illustrate similar-species groups. The following discussion details these modeled relationships and compares them to species' environments in other southeastern wetlands.

Hydrologic environments where most species occurred were not representative of conditions throughout the swamp where these species were absent. There were significant differences in inundation duration, inundation depth, and light availability conditions where species were present and absent across the landscape, and a gradient of differences in significant hydrologic parameters of all-sample models and species-present models. This indicates that many of the sampled species are specific in their hydrologic and light availability requirements; their distributions reflect a landscape that is hydrologically diverse, contributing to the heterogeneous landscape mosaic.

The long hydroperiod, deep water environments found in the aquatic prairies and the sill impoundment areas include associations of species that are differentiated by slightly different hydroperiods, water depths, and light availability variables (Tables 6-10 and 6-11). Fragrant water lilies and golden club are found primarily in long hydroperiod, moderately variable, deep water environments, where daily water depths averaged > 0.30 m during 40% of the time (1962-1995), and completely exposed conditions occurring occasionally (10% of the time). Although these species are also found at shallow depths and in partially shaded conditions, greatest coverage was in open water > 0.30 m deep, where ground level light is abundant. These conditions indicate inundation for longer periods than those found by Duever (1982), who estimated that fragrant water lily environments along the Okefenokee Swamp edge were without standing water for 44% of the 1941-1976 sampling interval. Richardson et al. (1995) found that fragrant water lily occurred in Lake Okeechobee, FL, in areas inundated for 93% of the study period (1970-1992), and David (1996) estimated a 96% inundation frequency with 61.5 cm average water depth for this species in Water Conservation Area 3A of the Florida Everglades. Wood and Tanner (1990) did not find fragrant water lily in association with a tall growth form of sawgrass (*Cladium jamaicense*) that occurred in areas with long hydroperiods and deep water, but found it in wet prairies characterized by deepest water depths and possibly shorter hydroperiods.

Three species of bladderwort (purple bladderwort, *Utricularia purperea*, floating bladderwort, *U. inflata*, rush bladderwort, *U. juncea)* were found in the understory plots where water depths were > 0.30 m for 42% of the time, with most frequent conditions

0.30-0.60 m deep; water depths were ≤ 0 m only 9% of the time. Purple and floating bladderworts were in greatest abundance in deep water conditions where ground level light was abundant and overstory cover was sparse; rush bladderworts occurred in saturated but usually not deeply-flooded sites, also where light was abundant (Bosserman 1983a). These differences probably contributed to the non-significance of depth-class in modeled descriptions of sites frequented by bladderworts, and resulted in a 3-dimensional plot that differed slightly from its frequent associate, fragrant water lily (Figure 6-8). David (1996) found similar variability in inundation frequencies (61.4-96.4% of 7 years) and average water depth (37 cm) where bladderworts occurred in the Everglades, and Richardson et al. (1995) estimated that sites with bladderworts were inundated during 97% of the 23-year study interval in Lake Okeechobee, FL. Although Wood and Tanner (1990) indicate that bladderworts occur in wet prairie environments of the Everglades, they did not quantify the extent or duration of flooding where this species occurred. None of these studies included species identification of encountered bladderworts.

Two other associations of species frequently occurred in long hydroperiod environments of deep water prairies, where water depths were slightly more shallow (0.15-0.60 m) and peat surfaces were more frequently exposed (13-25 % of the time). Chain fern, white arum, and Walter's sedge occurred in greatest abundance where water depths were 0.15-0.30 m or 0.30-0.60 m at least 50% of the time, and the peat surface was exposed approximately 20% of the time. These species occurred in sites with slightly shorter hydroperiods and shallower water depths than fragrant water lilies,

golden club, and bladderworts, and they were negatively associated with high light intensities. This contrasts with the results of Lucansky (1981), who found chain fern most abundant in sunny locations in North Florida. Wood and Tanner (1990) suggested that the occurrence of ferns and vines at the base of tall sawgrass in the Everglades area was in part due to the shallow water levels condition relative to the general wet prairie environment, and also due to shade provided by the sawgrass tussock.

The 3-dimensional plots of spatterdock, 3-square, spikerush, and *Sphagnum* spp. were similar to that of chain fern, white arum, and Walter's sedge; although the average conditions where spatterdock, 3-square, and *Sphagnum* spp. occurred were variable deep water, most-frequent occurrences were in water 0.05-0.30 m deep (spatterdock slightly deeper for longer period), with peat surface exposure approximately 20% of the time. The higher average water depth is most likely due to occurrence of these species in the sill impoundment area. Elsewhere water depths were considerably more shallow, which explains the position of spikerush in the moderate depth-moderate variability group. During 20-30% of the time, abundances of these species were associated with water depths < 0.05 m. This finding suggests that although these species are found in greatest abundance when water depths are generally 0.15-0.60 m, they can also tolerate variability in water depths, persisting during short-term drawdown when the peat surface is exposed. Spatterdock, 3-square, and spikerush were abundant in the seed bank of areas where they were also found in the standing vegetation (Chapter 7), in addition to spreading vegetatively or sprouting from rhizomes or tubers (Masters 1974), which may explain their return following inundation after exposure in variable environments.

Richardson et al. (1995), Gunderson (1994), and Wood and Tanner (1990) characterized the spikerush (*E. cellulosa* and *E. intersticta)* environment of the Everglades as "wet prairie", with average water depths of 77.5-93.8 cm and inundation occurring during 96% of the 23 year study period in Lake Okeechobee, FL (Richardson et al. 1995); Lowe (1986) measured an inundation frequency of 87-91% where *Eleocharis* spp. occurred in an East-central Florida marsh. Although these hydroperiod estimates are similar for those estimated in Okefenokee swamp for spikerush, the inundation depths are much greater. Light availability significantly influenced abundance of spikerush, and did not significantly affect abundance of spatterdock, *Sphagnum* spp., or 3-square. Shade inhibited growth and seed production of *E. obtusa* in experimental studies (Maillette and Keddy 1989); spikerush, which has a caespitose growth form similar to that of *E. obtusa,* may grow radially in response to low and patchy light levels, perhaps in an attempt to distribute the available light among all shoots (Maillette and Keddy 1989) while avoiding competition for space with vertically spreading, shade-intolerant species.

Sphagnum spp. occurred on sites exposed 20.4 $\pm$ 21.9% of the time. This genera has numerous adaptations for tolerating periodic drought (Andrus 1986), and varies growth form and rate with availability of moisture, light, and competition (Li and Glime 1990). *Sphagnum* spp. are capable of regenerating under exposed or inundated conditions and may occur in mats that have survived for many decades (Clymo and Duckett 1986), indicating that they are most likely capable of tolerating short-term, seasonal variability in the hydrologic environment that might leave the peat surface exposed.

Yellow-eyed grass, beakrush, hat pins, water willow, and tickseed were common in herbaceous prairies and aquatic prairie fringe, and occurred in relatively constant to moderately variable conditions where inundation depths were usually 0.05-0.30 m, and frequently 0.05-0.15 m. Peat surface exposure occurred < 15% of the time where these species were found. Other commonly co-occurring species are listed in Table 6-10. David (1996) found beakrush in the Everglades where water depths averaged 14 cm and inundation occurred during 53% of the 7-year sample period, and broomsedge (also occurring in Okefenokee Swamp herbaceous prairies), where water depths averaged 13 cm and inundation frequency ranged 0-100%. Broomsedge and beardgrass (*Erianthus giganteus*) were present historically in wet prairie areas sampled by Wood and Tanner (1990), but absent from their sampling. They attributed this change to prolonged flooding; however, depth of flooding may have been an equally significant limitation. Richardson et al. (1995) found yellow-eyed grass where hydroperiods were shorter and inundation less than areas occupied by water lily-bladderwort communities. No abundant species in their study occurred where hydroperiods were < 75% of the 23-year study period. Beakrush occurred in the marsh of a Florida lake margin, where it was inundated during 94% of 1971-1981 (Lowe 1990). Gerritsen and Greening (1989) found beakrush abundant in an Okefenokee Swamp aquatic prairie seed bank, but sparsely occurring in the standing vegetation. Its greatest abundance occurred during droughts, when beakrush seeds in the seed bank responded to exposure by germinating, and a new cohort of seeds was produced (Gerritsen and Greening 1989). During non-drought years it occurred sparsely on margins of islands. Rather than continuously compete for

resources with shallow water, long-hydroperiod species, beakrush may take advantage of occasional extreme conditions (drought) and rely primarily on rapidly producing propagules that may still be viable after 400+ years of submergence (Gerritsen and Greening 1989, Conti and Gunther 1984) in areas with longer hydroperiods and deeper inundation. Light level also affected abundance of beakrush; where abundant, ground level light correlated with greater amounts of beakrush. Other modeled herbaceous prairie species (yellow-eyed grass, hat pins, water willow, tickseed) were not significantly correlated with low level light availability.

Peat exposure occurred less often in the herbaceous prairies than in aquatic prairies, although herbaceous prairie water depths were on average shallower than those in the aquatic prairie environments (Table 6-4). This suggests some mechanism of water retention, by reduced run-off, minimal percolation, or low evapotranspiration rates. The overall topographic gradient across the swamp is from high elevations the Northeast to low elevations the Southwest. Along this trend are regions with perched surface water and minimal lateral water movement, creating a terracing effect in the water surface across the landscape (See Chapters 2 and 3). Durdin Prairie is in one of these terraces, which may partially explain the long hydroperiods in this area. Many areas of the swamp with herbaceous prairie vegetation also have flocculent peat and lack the firm peat bottom surface found in most aquatic prairies in the swamp. Flocculent peat occurs throughout Durdin Prairie, parts of Sapling and Floyd's Prairie in the vicinity of the Suwannee River floodplain, and some perimeter areas of Mizell and Chesser Prairies, and is likely in other areas not sampled. More frequent drawdown in the aquatic prairie

environment leads to compaction and oxidation of the peat surface, not experienced by the more continuously inundated surface in herbaceous prairie environments (Damman and French 1987). Along a transect in South Chesser Prairie, an up-welling of water (possibly a spring) was located within a few meters of an area of flocculent peat; this up-welling may maintain inundation in this area, even during periods of drought, creating this flocculent peat.

Wetland plants have mechanisms to acclimate to stresses of a flooded environment, such as cessation of gaseous exchange imposed by inundation. Formation of adventitious roots, aerenchyma tissue, hypertrophy of stem lenticels, secondary root formation, and formation of knees or pneumatophores are be structural changes to increase exchange of oxygen and waste products occurring in response to flood stress (Kozlowski 1984a, 1984b). Many plant species occurring in Okefenokee Swamp have these features. Many of the abundant herbaceous prairie species are monocots with tough leaves and parallel venation; this leaf structure decreases evaporative loss (Cherrett 1968). This feature may consequently increase the duration of flooded conditions in herbaceous prairies by retarding regional water loss due to evapotranspiration. Parallel venation also creates a leaf with high fiber content, which slows decomposition rates (Damman and French 1987). Dead vegetation accumulates in the absence of fire, and peat accumulates, eventually decreasing inundation of the peat surface. Therefore, species composition and abundance of peat in the water column may affect formation of floating islands and mats of vegetation, and subsequent succession from herbaceous prairie to wet forest.

Several species' groups occurred in the swamp where a variable hydrologic environment resulted in frequent peat surface exposure, although average water depths might be shallow or deep. Red root, maidencane, and Virginia willow have similarly shaped modeled surfaces indicating common relationships among variables and occurrences, with maidencane occurring at deeper and less frequently exposed sites. Red root and Virginia willow were found where peat surface was exposed nearly a third of the time, and the remainder of time most often inundated to 0.15-0.30 m. Virginia willow stems were usually located on hummocks or bases of trees, stumps, or decaying logs, giving them slight elevation above the surrounding inundated peat surface. Although maidencane had a similar model-surface shape, no flooding durations in particular depth classes were significantly related to maidencane cover. However, interactions of occurrences in shallow water, deep water, and no inundation were significant, indicating a variable hydrologic environment. David (1996) found maidencane in areas less frequently inundated (61%) but at similar water depths in the Everglades, whereas Wood and Tanner (1990) found maidencane in wet prairie environments with deep water and long hydroperiods, similar to sloughs described by Gunderson (1994). Lowe (1986) considered 87% inundation frequency optimum for maidencane coverage in a North-Florida lake margin, and Richardson at al. (1995) found maidencane at sites with a 23-year inundation frequency of 98%. This variability in water depth tolerance illustrates the plasticity of this species, which probably enables it to rapidly colonize recently exposed peat and then persist as standing vegetation and in the seed bank in the understory of developing islands (Cypert 1972), as well as in floating

mats in deeply inundated areas. Light levels did not significantly affect abundance of these species under fluctuating hydrologic conditions in Okefenokee Swamp.

Most tree and shrub species were found where exposure occurred about 25% of the time, and inundation depths were frequently 0.05-0.30 m. Abundant woody species were grouped into 5 associations based on shapes of 3-dimensional plots (indicating occurrence in exposed, shallow, and deep water conditions), water depth variability, and inundation depth. The associations are distributed along a gradient of water depth and variability. The moderately variable condition on the gradient is represented by pond cypress and red maple. These species had similar model-surface shapes, with red maple and pond cypress in slightly shorter hydroperiods and deeper water than loblolly bay, which has a similar modeled shape, but occurs in more constant conditions. Surface curvature in the 3-dimensional plots indicated significant interactions between frequency of exposed conditions and shallow water depths for red maple and pond cypress; abundances of red maple and loblolly bay were also higher with less time spent in deep water than pond cypress. Red maple is not normally found where deep flooding occurs during the growing season (Penfound 1952). Patrick et al. (1980) estimated that red maple generally occurs where soils are temporarily saturated or inundated for short durations (10-50%) of a year. Red maple in the Okefenokee Swamp averaged 40.0% $\pm$ 17.9% inundation duration to 0.08 m $\pm$ 0.19 m average water depth. Monk (1966) measured similar relationships among red maple, loblolly bay, and pond cypress in North-central Florida hardwood swamps, and Harms et al. (1980) recorded significant, increasing mortality in red maple where water depths were greater than 25 cm. After 6

years of flooding to an average daily water depth of 66 cm, red maple mortality was 22-100% in the impounded Ocklawaha River, Florida (Harms et al. 1980).

The ability to produce adventitious roots when prolonged flooding occurs is related to flooding tolerance (Hook and Brown 1973). Although red maple and pond cypress can produce these roots, they did not do so everywhere in Okefenokee Swamp; adventitious roots were present on pond cypress only in the immediate vicinity of the sill and were not found on red maple in any of the sampled area of the swamp. Soils must be nearly continuously inundated to necessitate development of adventitious roots in most species with this capability; infrequent or annual periodic flooding does not usually result in their production (Harms 1973, Hook et al. 1972, 1971, 1970). This suggests that the level of flooding experienced by these species in areas outside of the impounded area (i.e., radiating north from Billy's Lake) in the Okefenokee Swamp was not prolonged enough to initiate production of these structures used in supplemental aeration.

The model surfaces that describe the relationships among the hydrologic variables and occurrences of swamp blackgum, sweet bay, and dahoon holly are similar to those of red maple, pond cypress, and loblolly bay. Significant model parameters suggest that red maple, pond cypress, and loblolly bay densities increase with slightly longer duration of shallow flooding, whereas swamp blackgum, sweet bay, and dahoon holly abundances increase with increasing length of surface exposure. Peat was exposed 25-30 % of the time where blackgum, sweet bay, and dahoon holly occurred. Swamp blackgum occurred where water depths fluctuated between no inundation and shallow flooding, with most frequent water depths ≤ 0.60 m; although it can withstand deeper

inundation, blackgum productivity and recruitment are reduced by prolonged flooding (Harms et al. 1980, Patrick et al. 1980, Gill 1970, Monk 1968). Over a 6-year period, swamp blackgum mortality on the impounded Ocklawaha River was 20-55 % when trees were inundated to 125 cm (Harms at al. 1980), and remaining trees in 82-107 cm of flooding were in poor condition but appeared to have survived the long-term inundation. Red maple mortality approached 80% under those conditions (Harms et al. 1980). Sweet bay and dahoon holly abundances were significantly greater on Okefenokee Swamp sampled transects when water depths average ≤ 0 m.

Although the modeled surfaces illustrate similar trends among woody species' occurrences (Tables 6-8, 6-9, 6-10, and 6-11), there are subtle differences that distinguish where these species might occur. Fetterbush, hurrahbush, bamboo greenbriar, Walter's greenbriar, titi, and climbing fetterbush were found primarily at sites with average water depths 0.06-0.11 m, moderate exposure, and most frequently between no inundation and water depths of 0.05-0.30 m. Hurrahbush and fetterbush occurred at moderately variable (SD = 0.11m) shallower sites (most frequent water depths for hurrahbush 0.15-0.30 m, and for fetterbush 0.05-0.15 m). Fetterbush occurred more often with abundant ground level light, whereas sites with hurrahbush were generally more densely vegetated and had minimal ground level light. When considering only shallow water depths, duration of inundation was a significant parameter in predicting hurrahbush abundance, but fetterbush abundance was more significantly limited by abundant overstory cover and scarce ground level light. This finding agrees with Hamilton (1984, 1982), Deuver and

Riopelle (1983a, 1983b), and Cypert (1961), who recognized fetterbush as an early woody colonizer of exposed peat, and hurrahbush as a later succession, midstory species.

Titi and Walter's greenbriar are found in wetter environments than fetterbush and hurrahbush. Walter's greenbriar is found primarily in water depths of 0.15-0.30 m, while titi also occurs at depths > 0.30 m. Locations where Walter's greenbriar occur have a higher exposure frequency than those with titi. Abundances of neither species were significantly correlated with light availability. Walter's greenbriar is found in the understory in canopy gaps as well as in the canopy of low shrubs. Titi frequently forms the canopy in early stages of peat-based island formation, and is gradually replaced by hurrahbush and fetterbush as the vegetation ages (Glasser 1986, 1985, Best et al. 1984, Hamilton 1984, 1982, Deuver and Riopelle 1983a, 1983b, Deuver 1979), although it may persist in patches of sparse overstory.

Bamboo greenbriar is found in areas of lower inundation depths but less frequent exposure than Walter's greenbriar. Greatest densities occur where water depths are 0.05-0.15 m and overstory cover is abundant. Bamboo greenbriar occurs in much greater density than Walter's greenbriar in the swamp, and frequently grows into the tree and shrub canopy, creating an impenetrable blanket of vines across crowns of the woody species that give it support. It generally appears earlier in successional development than Walter's greenbriar (Cypert 1961).

Climbing fetterbush is a unique species in the swamp; it usually does not root in the peat directly but grows in the crevices of pond cypress bark, and therefore occurs with a range of exposures and water depths. Its modeled surface most closely resembles

bamboo and Walter's greenbriar, which also use shrub and tree growth for physical support. Unlike the greenbriars, however, climbing fetterbush does not occur in abundance in the canopy; it is in greater densities where ground level light is abundant, which frequently is under a dense, high canopy. Stem densities are highest at sites that are frequently inundated > 0.30 m, which does not correspond to highest densities of pond cypress (0-0.30 m water depth). Overstory cover may exclude climbing fetterbush where pond cypress densities are high. This species is not usually found in early successional stages.

Vegetation Changes Due to Sill Impoundment Effects

The hydrology model predictions of areas in the swamp that are currently experiencing increased water depths and inundation durations were discussed in Chapter 3 and are delineated on Figure 3-9. The increasing hydroperiods and water depths due to the sill impoundment have created an additional environment in the swamp close to the sill structure that was not previously present in that area, and species associated with this environment are currently unique to that part of the swamp. Prior to sill construction, the region directly north and east of the sill was a seasonally flooded pond cypress-swamp blackgum-pine forest with myrtle-leaved holly (*Ilex myrtifolia*), loblolly and sweet bay, and red maple scattered throughout. Marketable pines were removed from the area before flooding, and the area currently is vegetated with various-aged groups of pond cypress and swamp blackgum, with occasional bays, maple, and ash; pines occur only to the west of the sill where they were not logged during sill construction. Carolina

ash and ogeechee lime (*Nyssa ogeechee*) currently are found within the river floodplain from the sill northeast to the natural sill. Ogeechee lime is limited to the river banks and river floodplain above and below the sill structure, and also along the northwestern swamp beyond the area of the sill's influence in slow-flowing creeks. Carolina ash is scarce throughout the floodplain south of the natural sill, and infrequent elsewhere in the swamp; its distribution prior to sill construction is uncertain, although conditions were probably favorable for its occurrence in this area of the swamp. Penfound (1952) found Carolina ash in temporarily flooded flats and sloughs, frequently following fires, and probably transitional between swamp and mesic forest. Monk (1966) categorized Carolina ash with other mixed hardwood swamp species (sabal palm, *Sabal palmetto*; American elm, *Ulmus americana*; bald cypress, *Taxodium distichum*), where flooding is seasonal and variable and peat accumulation is minimal. Monk (1966) found these species similarly distributed along a water depth-pH-cation gradient in North-Central Florida hardwood swamps; he suggested that the gradient represented a transition from hardwood and bayhead communities. Monk (1968) also found mixed hardwood swamps in vicinity of limestone outcroppings in Florida; Trowell (pers. comm.) believes there are similar outcroppings in the sill area within the swamp. Hamilton (1984, 1982) hypothesized that mixed swamp was a mature stage in the swamp in the absence of fire. In the remainder of the sill-affected area, extended flooding and deeper water depths favorable to aquatic prairie development have occurred, and germination of species requiring exposure has probably been reduced. However, flood-tolerant species that

could establish during drawdown in sufficient light (such as pond cypress, blackgum, and ogeechee lime) have also persisted.

The region currently impounded by the sill would most likely encounter increased exposure duration and variability with complete sill removal, and experience an intermediate level of change with partial sill removal. In some of this affected area the degree of hydroperiod and depth changes would be sufficient to stimulate changes in vegetation composition. Competitive interactions among species, availability of propagules, and stage of successional development will modify this response.

Changes in hydroperiods and water depths predicted in response to sill removal will not be uniform across the sill-affected area (Table 6-12). The region around the sill structure to Craven's Hammock and eastward to Billy's Lake, including the Suwannee River floodplain will experience more variability in water levels with a decline in deep water depths ($\geq$0.30 m), and greater decline in depths and increased variability closer to the sill structure and creek and river channels (Table 6-12). Open canopy in the Craven's Hammock area will be more favorable for shallow prairie vegetation and shrub and tree reproduction. Although water levels will be more variable and therefore more favorable than current conditions for pond cypress regeneration, this species will probably be replaced in much of this area with loblolly and sweet bay and blackgum; although some cypress seed source exists in the area, bays compose much of the canopy and create shaded ground level conditions not tolerated by germinating cypress (Best et al.1984, Demaree 1932). Cypress regeneration will be limited to large canopy gaps currently near seed source trees or within the area likely flooded by seasonal water, unless severe fires

occur which open the canopy and remove the surrounding bays and blackgum. However, severe fire could also reduce seedling survival (Cook and Ewel 1992).

As predicted by the swamp hydrology model, water depths in the region bounded by Sapling Prairie southeast to Chase Prairie and possibly southwestern Territory Prairie, and southwest to Billy's Lake will decline ≤ 0.30 m, with slightly more variability in the southwest, with sill removal (Table 6-12). These conditions will be more favorable for shallow, herbaceous prairie species, although aquatic prairie species will persist in areas with deeper water levels. Because much of this area is currently forested with bays, surface water flows are limited, and pond cypress is generally limited to prairie islands and isolated forest stands, there will probably not be a significant increase in pond cypress in this area, and areas forested in gums and bays will persist. In shallow open areas loblolly bay, which has wind-dispersed seeds, will probably be the most substantially increasing woody species. Currently loblolly bay is dispersed throughout the area, and seedlings are encroaching into eastern Floyd's Prairie from the Floyd's Island southwestern perimeter. Within this region, Floyd's Prairie will probably experience the greatest change, with increasing woody growth (primarily tit and loblolly bay)and less dramatic changes occurring in Sapling and Chase Prairies. Because Territory Prairie is terraced above Chase Prairie, change in hydroperiods that would lead to altered vegetation will probably be minimal; this region is currently affected by the sill impoundment primarily during periods of abundant precipitation, when water levels are high and constant.

The region bounded by Cypress Creek, Sapp Prairie, and Sweetwater Creek will also experience hydrologic changes with sill manipulation (Table 6-12). Cypress Creek will probably experience greater water level fluctuation and may experience extended exposure. Although Sapp Prairie and Sweetwater Creek may also have decreased high water depths, they will probably not experience the increase in exposure predicted for the Cypress Creek area. Sill removal will permit a greater volume of throughflow in the Suwannee River at the Cypress Creek-Suwannee River junction, which may slow drainage from Cypress Creek during high water events. However, during low precipitation periods, the river flow volume will decline more rapidly than with the sill in place, and flow from Cypress Creek will also rapidly decline. Vegetation changes in the area will probably be minimal, because most of the area is currently forested with shrub and wet pine communities and herbaceous prairie vegetation where openings exist. This area has experienced frequent fires since the sill's construction, maintaining these vegetation types which also occurred in the area before sill construction. Much of Sapp Prairie is slowly succeeding to shrub prairie; with sill removal, this trend will continue unless severe fires occur in the next decade. In the remainder of the swamp, vegetation changes that can be attributed to sill removal will be minimal; the absence of fire will be the primary function driving swamp succession.

CHAPTER 7
RESPONSE OF THE OKEFENOKEE SWAMP SEED BANK
TO ALTERATIONS IN THE HYDROLOGIC ENVIRONMENT

Introduction

Accumulated seeds in sediments, or the seed bank, are a dormant reserve providing propagules for vegetation community establishment and maintenance, and recovery from extreme conditions and disturbances. The standing vegetation may be represented in this reserve, permitting perpetuation of the vegetation community as long as suitable conditions exist and seeds remain viable. Distinct patterns in the adult distributions may be mirrored in seedling and seed distributions; however, generalized tolerances of a broad gradient of conditions during recruitment may increase propagule and seedling survival and result in broad distributions of adult plants (Keddy and Ellis 1985) so that zonation is not apparent. The established vegetation also may be persisting in conditions unsuitable for development of its propagules; changes in the site environment as the seedling matures may prohibit establishment of its own offspring at the site. The seed bank may also include seeds from species that have been removed from the site's standing vegetation through competitive interactions, succession, animal or human activities, or disturbances such as fire. Species that did not previously occur in

the site's standing vegetation may also be present in the seed bank, transported to the site by water, wind, or animal movement. Survival and germination of these seeds depends on exposure to conditions that will break seed dormancy after deposition at a suitable site for seedling growth. When appropriate conditions for seed germination occur, competitive interactions and sensitivities to current and changing site conditions determine which seedlings will survive, reproduce, and contribute to the seed bank.

Environmental conditions affect seed longevity and seedling recruitment from the seed bank (van der Valk 1981). Buried seeds in a wetland must survive anaerobic conditions in waterlogged sediments, and may have to tolerate inundated conditions as the seedling emerges. Those that can not germinate in flooded soils must wait for drawdown and soil exposure to occur. Changing nutrient dynamics, decomposition processes, and alterations in competitive interactions occur with increasingly aerobic conditions as water levels decrease and sediments are exposed. Seed bank compositions may serve as indicators of past wetland hydroperiods (Poiani and Johnson 1989). Slight modifications in inundation depths or durations can alter the composition of standing vegetation (see Chapter 6) and subsequently seed bank composition; changes in successional patterns may then follow (van der Valk 1981).

Seasonal weather patterns may create suitable conditions frequently (e.g., annually), so that perpetuation through long-term dormancy in the seed bank is unnecessary for some species. Those species persisting in the vegetative state can respond to short-term, favorable changes in environmental conditions through vegetative propagation or seed production. Alternating dry and wet conditions may also release a

suite of species unlike those persisting in continually dry or inundated conditions (Gerritsen and Greening 1989, Greening and Gerritsen 1987) and may affect survival of dormant seeds that need continuously inundated or exposed conditions for germination (Berrie and Drennan 1971). Severe or less predictable conditions such as drought lead some species to another strategy; these species persist as seeds that germinate only under infrequently occurring conditions, rapidly maturing and producing abundant seeds, and then residing again as seeds in the sediments, as competitive interactions with more persistent species increase (Grubb 1998). Elimination of the occasional disturbances such as severe drought and fire, or changes to the ambient hydrologic environment, may eventually displace species that perpetuate episodically in response to these unpredictable environmental fluctuations. Those that depend on general but predictable environmental conditions will also be displaced if environmental changes exceed their plasticity; a different community composition and landscape structure will eventually result.

The Suwannee River sill was constructed to reduce frequency, extent, and intensity of wildfires by continuously flooding the swamp with the impounded Suwannee River, regardless of precipitation conditions The extended inundation duration and increased water depths resulting from the Suwannee River sill (see Chapter 3) have the potential to alter swamp vegetation community compositions and distributions locally in the hydrologically affected area (see Chapter 3 and Chapter 6). The sill may have affected the seed bank composition in this area by changing the composition of standing vegetation in response to continual flooding. In the sill-affected area opportunity for

recruitment of species requiring exposure for germination has decreased; potential for future expression of those species in the standing vegetation declines with continued sill operation, as seed viability in the inundated conditions decreases over time (Schneider and Sharitz 1988, 1986).

Indirect, landscape-level changes may also be occurring in response to the sill impoundment; extended, deep flooding limits regeneration of species such as pond cypress (*Taxodium ascendens*) that require exposed surfaces for germination. Decreasing densities of pond cypress in the forest composition may affect response to wildfires, as fire-tolerating species such as pond cypress, which requires open canopy for seedling survival, are replaced by those with fire-suppressing characteristics (see Chapter 5). Pond cypress tolerates fire that may control or eliminate competing shade-tolerant and fire intolerant hardwood species in the surrounding forest. Although lack of wildfire in the impounded area can not be directly attributed to the sill impoundment affects, poor pond cypress regeneration due to extended hydroperiods and subsequent changes in species composition to less fire-tolerating or fire promoting species will create a positive feedback loop that eventually affects the area's fire regime. Reduction or elimination of pond cypress from the forest canopy is eventually possible if wildfires do not occur frequently and severely enough to remove its competitors (Best et al. 1984).

The conditions of extended flooding have been exacerbated in the swamp by early 20th century logging activities (see Chapter 4), which removed or damaged much of the cypress and subsequently altered the regenerative potential of this community (Hamilton 1984, 1982). Decisions to alter the sill structure must consider the delayed

and long-term impacts of logging. Decreasing the inundation duration of the sill-affected area and permitting greater amplitude of seasonal fluctuations in water levels and flooding duration with sill removal will improve conditions for floodplain species that survived the early 20th century logging. However, species that have not persisted in the area's seed bank or standing vegetation, and that have not been brought into the area by wind or surface water movement, will be absent from the area until transported in as seeds or vegetative sprouts from other parts of the swamp and its perimeter.

Dependence on the swamp seed bank to repopulate (to pre-sill composition) areas that might experience changes in the hydrologic environment with sill manipulation prompted the following questions, which are addressed in this chapter:

1) What is the seed bank composition in the sill-affected area, and does it differ from that of the surrounding swamp?

2) Do the seed bank contents differ from the site's standing vegetation composition?

3) Is the seed bank composition representative of the site's hydrologic environment and recent history?

4) What is the potential response of the seed bank to exposed and inundated conditions that might occur with sill modification?

Methods

Seed Bank Sampling

Emergence techniques (counts of seedlings germinating from seed bank samples housed in a greenhouse) were used to identify and quantify the swamp seed bank composition and response to hydrologic manipulation (e.g., Grillas et al. 1992, Poiani and Johnson 1988). During October (autumn samples) 1992 and 1993 and May (spring samples) 1993 and 1994 seed banks were sampled along transects in the 5 regions of the swamp where standing vegetation composition was assessed for species-hydrologic environment relationships (see Chapter 6). Half of the 16 transects in each area were randomly selected for seed bank assessment. These transects were also sampled for shrub and tree composition, as discussed in Chapter 6. Seed bank samples were collected within the structural zones identified for standing vegetation composition assessment. Collection of samples across the variety of structural zones existing in the sample areas provided an opportunity to examine differences in seed bank composition among successional stages (Leck 1989). Within each structural zone 6 cylindrical peat cores (approximately 20 cm deep x 20 cm diameter) were removed from sites proximal to the transect understory plots, within approximately 5 m of the transect and sampled plots (Figure 7-1). Sample depth was selected based on estimates of Gunther et al. (1984), that >90% of the viable seeds collected from wooded forest and open marsh areas of Okefenokee Swamp resided in the top 20 cm of peat. Several small samples

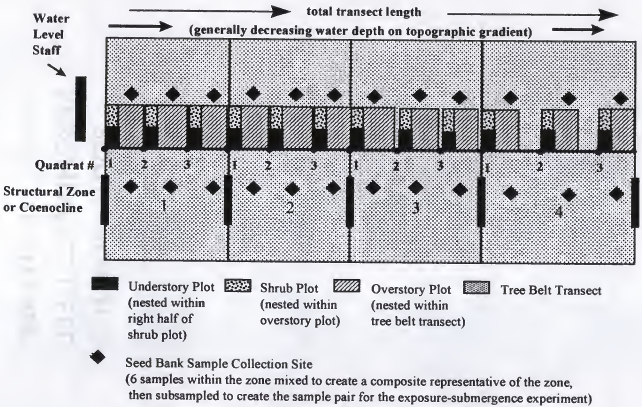


Figure 7-1. General scheme of seed bank sample collection sites, relative to other vegetation sample plots, along transects in Okefenokee Swamp.

were anticipated to better represent structural zone seed banks than few, large samples (Thompson 1986). The 6 cores were combined in a large tub; live and undecomposed, dead materials were removed; and, the core material was thoroughly mixed to create a composite representative of the variability throughout the entire sampled zone. A subsample (approximately 4 l) was removed from the composite sample and stored in marked plastic bags for transport to the greenhouse near the Okefenokee Swamp National Wildlife Refuge, Camp Cornelia Visitor's Center, south of Folkston, GA.

In the greenhouse (within 12 hours of sample collection) the 4 l sample was halved and spread in a 2 cm thick layer in 2 plastic, potted-plant drainage pans (approximately 30 cm diameter x 7 cm deep) with perforated bottoms. Pairs of pans from each transect zone were randomly placed in the greenhouse in spillways (4, approximately 1 m x 12 m x 0.3 m) that were continuously flooded with swamp water pumped from the bottom of the boat basin canal near Camp Cornelia Visitor's Center. Water entered the spillways at the northwestern end, and flowed through the spillway to the south end, where it was gravity-drained back into the canal (Figure 7-2). One sample in each pair was placed on the spillway floor and the other was perched adjacent to it at the water surface on a brick. The brick held the sample approximately 4 cm above the spillway floor so that the sample surface remained moist by wicking water through the pan base without flooding the peat surface. The other member of the pair was inundated with approximately 2 cm of water that wicked through the pan base but did not overflow the pan edge. Thus the sample surfaces were kept isolated from the flowing water surface except through wicking through the pan bottom; this was intended to keep seeds

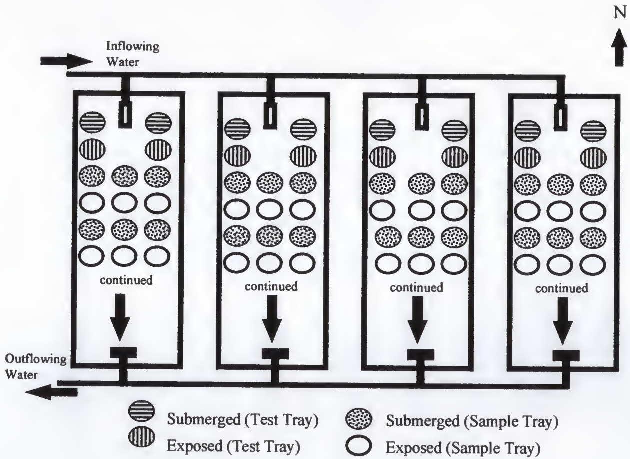


Figure 7-2. Seed bank emergence experiment sample layout in greenhouse with continuous swamp water irrigation system.

that might be in the irrigation water from contaminating the sample surface. A pair of potting soil samples (2 l in each) was similarly placed at the north end of each spillway to intercept irrigation water as it initially entered the spillways; these samples were intended to indicate the seed contents of incoming irrigation water. At the end of each sample interval, none of these trays contained seedlings of species found in the peat samples. Therefore, it was concluded that the seedlings emerging from the peat samples originated as seeds at the collection sites and were not carried in irrigation water. The continuously inundated or exposed treatments were selected based on Gerritsen and Greening's (1989) conclusion that germination of Okefenokee Swamp seed bank species was under either of these conditions.

Although the greenhouse environment offered some protection for autumn samples from winter freezing temperatures, seasonal dynamics in air and water temperature and sunlight availability in the greenhouse generally reflected those in the surrounding swamp. Samples were not permitted to desiccate during periods of normally low water levels in the swamp. Surface peat at the collection site did not naturally desiccate during the study interval, although drawdown, peat exposure, and desiccation occasionally occur at some of the sample sites. Natural lighting was not supplemented during the germination periods. The duration of the germination period was determined by a general cessation of seedling emergence in September and February following spring and autumn sample periods, respectively. In September (following spring sampling) and February (following autumn sampling), all seedlings were removed from the sample trays, identified, and counted (Poiani and Johnson 1988). Seedlings that

could not be identified were retained in the sample trays until maturity made their identification more apparent. If seedlings matured to produce seeds during the sample period, the plant was removed from the sample tray at the peat surface to eliminate contamination with seed dehiscence in surrounding samples.

Analysis of Seed Bank Emergence Data

Descriptions of the transect herbaceous and woody vegetation and hydrologic environment were outlined in Chapter 6. Species composition in the understory plots was summarized across the zone, and understory plot hydrologic data were similarly averaged to describe the zone hydrologic environment where the sample originated. Counts of emerging seedlings were log-transformed ($\log_{10}$ count +1) to normalize their distributions, and compared by seasons (spring, autumn) among sample areas (Chesser Prairie, Durdin Prairie, Sapling Prairie, Floyd's Prairie, Sill Area), structural zones (Table 6-1), treatments (submerged or exposed), and their interactions using a nested model ANOVA (*Proc GLM*, SAS Institute, Inc., Cary NC 27513). Parameters with significant effects were identified with mean comparisons using specified error mean squares. Overall comparisons between seasons were made with t-tests. Sample tray species diversity, species richness, and total seedling counts were similarly compared among areas, treatments, zone types, and seasons, as were species' groups based on general water depth and variability trends (see Chapter 6).

Results

Species' Responses

Forty-nine species (Table 7-1) germinated in the seed bank samples, representing a variety of vegetation community types in the swamp, although not all species in the standing vegetation were included in the seed pool (Table 7-2). Germination of woody species was sparse (Figure 7-3), which is not an uncommon feature of wetland seed banks (Leck 1989, Schneider and Sharitz 1986). Nine herbaceous species comprised 93.4% of the germinated seeds; 71.2% of the emerging seedlings were yellow-eyed grass (*Xyris* spp.) (Table 7-1). Woody plants accounted for <0.1% of the germinated seeds, and titi (*Cyrilla racemiflora*) was the most abundant of these species (Table 7-1). No species were found in the seed bank that were not also found somewhere in the swamp standing vegetation (although not necessarily along sample transects), and the standing vegetation composition at the collection site did not always correspond to the composition of germinated seeds from the site (Table 7-3).

Total number of emerging seedlings did not differ among seasons, but did vary with area, zone, and treatment (Table 7-4). Diversity of the seed bank was also significantly affected by area, zone, and treatment, but seasonal differences were minimal (Table 7-4). Autumn species diversity was greatest in samples from tree, aquatic prairie, shrub-aquatic prairie, and tree-aquatic prairie, and in the spring was also high in samples from herbaceous prairie and aquatic-herbaceous prairie structural zones

Table 7-1. Species germinating in the seed bank samples, and their distributions among areas, seasons, and treatments.

Species	Overall Seedling Density ($\#/m^2$) and Total Count (n=1302)	Chesser Prairie Seedling Density ($\#/m^2$)	Durdin Prairie Seedling Density ($\#/m^2$)	Floyd's Prairie Seedling Density ($\#/m^2$)	Sapling Prairie Seedling Density ($\#/m^2$)	Sill Area Seedling Density ($\#/m^2$)	Exposed Treatment Seedling Density ($\#/m^2$)	Submerged Treatment Seedling Density ($\#/m^2$)	Spring Seedling Density ($\#/m^2$)	Autumn Seedling Density ($\#/m^2$)	H_o: Seasonal Difference In Means = 0 ? P > t	H_o: Seasonal Difference In Variances = 0 ? P > t
Andropogon/ Erianthus	1.7 144	0.2 - [a]	6.3 *	0.3	0.1	0.1	1.8	1.5	1.7	1.7	0.7800	0.4766
Bidens mitis	0.4 31	0.0	1.2 *	0.2 -	0.0 -	0.1 -	0.6	0.1	0.2	0.5	0.5924	<0.0001
Carex walteriana	1.4 124	1.2 -	1.7 -	2.2 *	1.4 *	0.2 -	2.4	0.5	0.5	2.4	0.0001	<0.0001
Clethra alnifolia	<0.1 1	0.0 -	0.0	0.0 *	0.0 -	0.1 -	<0.1	0.0	0	<0.1	0.3177	b
Cyperus erythrorhizos	0.2 14	0.1 -	0.2 -	0.2 -	0.0 -	0.4 -	0.3	0.1	0.2	0.2	0.8441	0.4752
Cyrilla racemiflora	0.2 19	0.4 *	0.1	0.1	0.2 *	0.4	0.4	0.1	0.3	0.1	0.1150	<0.0001
Decodon verticillatus	0.1 8	0.0 -	0.0 *	0.0 -	0.0	0.7	0.2	0.0	0.1	0.1	0.7867	0.4233
Drosera intermedia	15.9 1390	15.0 -	24.1 *	1.6 -	34.2	0.0 -	17.7	13.9	14.5	17.2	0.0976	0.2193
Dulichium arendinaceum	32.9 2869	67.6 *	40.8	14.4	5.5	29.1	47.4	16.9	26.4	37.8	0.0004	0.0005
Eleocharis baldwinii/ vivipara	37.1 3234	60.1	24.9	20.5	14.5	76.4 *	56.4	16.2	28.5	43.9	0.0001	0.0021
Eleocharis robbinsii	12.8 1118	15.7	5.0 -	21.1 *	19.4	0.6	12.2	12.6	15.6	9.1	0.0001	<0.0001

Table 7-1--continued.

Species	Overall Seedling Density (#/m^2) and Total Count (n=1302)	Chesser Prairie Seedling Density (#/m^2)	Durdin Prairie Seedling Density (#/m^2)	Floyd's Prairie Seedling Density (#/m^2)	Sapling Prairie Seedling Density (#/m^2)	Sill Area Seedling Density (#/m^2)	Exposed Treatment Seedling Density (#/m^2)	Submerged Treatment Seedling Density (#/m^2)	Spring Seedling Density (#/m^2)	Autumn Seedling Density (#/m^2)	H_o: Seasonal Difference in Means = 0 ? P > t	H_o: Seasonal Difference in Variances = 0 ? P > t
Erianthus giganteus	0.2 15	0.1 -	0.4 -	0.2 -	0.1 -	0.1 -	0.3	<0.1	0.0	0.3	0.0026	b
Gordonia lasianthus	0.1 7	0.0 *	0.0	0.0 -	0.2	0.3 -	0.1	<0.1	0.1	0.1	0.8393	<0.0001
Ilex cassine	<0.1 1	0.0	0.0	0.1 *	0.0 *	0.0	<0.1	0.0	0.1	<0.1	0.3177	b
Iris virginiana	0.1 4	0.2	0.0	0.1 *	0.0	0.0 -	0.1	0.0	0.0	0.1	0.0915	b
Itea virginica	<0.1 1	0.0	0.0 -	0.0 *	0.0	0.1	0.1	0.0	0	<0.1	0.3177	b
Juncus repens	38.2 3329	0.0 -	0.0 -	0.0 -	0.0 -	270.0 -	68.6	8.4	48.6	28.6	0.5031	0.0002
Juncus triganocarpus	0.4 34	0.1 -	0.0 -	0.0 -	0.0 -	2.6 -	0.7	0.1	<0.1	0.7	0.0431	<0.0001
Lacnanthes caroliniana	48.8 4256	61.1	57.8 *	83.6	13.2	11.0	84.3	12.9	58.5	37.7	0.0001	0.0010
Leucothoe racemosa	0.1 9	0.1	0.2	0.1	0.2	0.0 *	0.2	<0.1	0.1	0.1	0.7702	0.0287
Ludwigia alata	6.1 536	8.4 -	1.4 -	14.8 -	2.4 -	3.0 *	7.0	5.2	5.7	6.5	0.8992	0.3492
Lyonia lucida	0.1 10	0.3 *	0.1 *	0.1	0.1	0.1 -	0.2	0.0	0.2	0.0	0.0184	b

Table 7-1--continued.

Species	Overall Seedling Density (#/m²) and Total Count (n=1302)	Chesser Prairie Seedling Density (#/m²)	Durdin Prairie Seedling Density (#/m²)	Floyd's Prairie Seedling Density (#/m²)	Sapling Prairie Seedling Density (#/m²)	Sill Area Seedling Density (#/m²)	Exposed Treatment Seedling Density (#/m²)	Submerged Treatment Seedling Density (#/m²)	Spring Seedling Density (#/m²)	Autumn Seedling Density (#/m²)	H_o: Seasonal Difference in Means = 0 ? P > t	H_o: Seasonal Difference in Variances = 0 ? P > t
Lyonia sp.	<0.1 3	0.1 -	0.0 -	0.0 -	0.1 -	0.1 -	0.1	<0.1	0.1	0.0	0.0833	b
Nuphar luteum	2.7 232	0.4 -	1.5	0.2 -	1.2 -	13.6 *	0.8	4.1	1.0	3.9	0.0004	<0.0001
Nymphaea odorata	46.3 4036	43.8 *	88.8	14.4	14.1	68.1 -	38.4	55.0	41.5	51.9	0.2188	0.0384
Nyssa sylvatica v. *biflora*	<0.1 3	0.0 -	0.0 -	0.0 -	0.0	0.2 *	0.1	0.0	0.1	0.0	0.1680	b
Orontium aquaticum	<0.1 2	0.0 *	0.0	0.1	0.1	0.0 -	0.0	0.1	0.0	0.1	0.1575	b
Panicum hemitomon/ Sacciolepis striata	3.8 330	0.2	0.0	0.4	0.5 *	25.2 *	7.3	0.3	3.0	4.7	0.2218	<0.0001
Rhynchospora alba	0.6 48	0.2 -	2.2 -	0.0 -	0.0 -	0.0 -	1.0	0.1	1.0	0.1	0.0028	<0.0001
Rhynchospora cephalantha/ microcephala	1.2 106	0.9 -	3.4 -	0.2 *	0.8 -	0.2 -	1.7	0.8	0.4	2.1	0.0908	<0.0001
Rhynchospora fascicularis/ wrightiana	18.8 1637	26.1 -	47.3 -	0.7 -	7.6 -	0.6 -	32.2	5.5	14.6	22.9	0.4630	<0.0001
Rhynchospora inundata	26.3 2296	39.5 -	4.9 *	57.4 -	23.2 -	0.5 -	38.5	14.7	34.6	18.6	0.0001	<0.0001

Table 7-1--continued.

Species	Overall Seedling Density (#/m^2) and Total Count (n=1302)	Chesser Prairie Seedling Density (#/m^2)	Durdin Prairie Seedling Density (#/m^2)	Floyd's Prairie Seedling Density (#/m^2)	Sapling Prairie Seedling Density (#/m^2)	Sill Area Seedling Density (#/m^2)	Exposed Treatment Seedling Density (#/m^2)	Submerged Treatment Seedling Density (#/m^2)	Spring Seedling Density (#/m^2)	Autumn Seedling Density (#/m^2)	H_o: Seasonal Difference in Means = 0 ? P > t	H_o: Seasonal Difference in Variances = 0 ? P > t
Rhynchospora spp.	1.4 123	1.5 -	2.5 *	1.2 -	0.9 -	0.4 -	1.9	1.0	0.3	2.6	0.0001	<0.0001
Sagettaria graminea	2.2 195	4.5	3.6 *	1.0 *	0.9	0.0 -	1.8	2.7	2.4	2.0	0.2626	0.1288
Sarracenia flava	0.1 4	0.0 -	0.2 *	0.0	0.0 -	0.0 -	0.1	0.0	0.1	0.0	0.1799	b
Sarracenia psittacenia/ flava	<0.1 1	0.0	0.1 *	0.0 -	0.0 -	0.0 -	<0.1	0.0	<0.1	0.0	0.3177	b
Scleria reticularis	0.3 25	0.7 -	0.2 -	0.4 -	0.0 -	0.0 -	0.5	0.1	0.4	0.2	0.2963	<0.0001
Smilax laurifolia	0.1 6	0.1	0.1*	0.0	0.1	0.1 -	0.1	0.0	<0.1	0.1	0.5283	<0.0001
Smilax walteri	0.1 5	0.1 -	0.1 -	0.1 *	0.0	0.1	0.1	0.0	<0.1	0.1	0.2681	<0.0001
Smilax spp.	0.1 4	0.1 -	0.1 -	0.0 -	0.1 -	0.0 -	0.1	0.0	<0.1	0.1	0.8389	0.0051
Syngonanthus/ Eriocaulon	25.2 2201	13.4	84.8 *	3.2 -	6.4 -	0.5 -	38.7	11.7	4.8	45.9	0.0001	<0.0001
Syngonanthus flavidulus	8.8 767	4.5	31.1 *	0.1 -	1.8 -	0.0 -	5.2	12.6	13.6	4.1	0.0001	<0.0001
Taxodium ascendens	<0.1 1	0.0 -	0.0 *	0.0	0.1	0.0	<0.1	0.0	<0.1	0.0	0.3177	b

Table 7-1--continued.

Species	Overall Seedling Density (#/m²) and Total Count (n=1302)	Chesser Prairie Seedling Density (#/m²)	Durdin Prairie Seedling Density (#/m²)	Floyd's Prairie Seedling Density (#/m²)	Sapling Prairie Seedling Density (#/m²)	Sill Area Seedling Density (#/m²)	Exposed Treatment Seedling Density (#/m²)	Submerged Treatment Seedling Density (#/m²)	Spring Seedling Density (#/m²)	Autumn Seedling Density (#/m²)	H_o: Seasonal Difference In Means = 0 ? P > t	H_o: Seasonal Difference in Variances = 0 ? P > t
Triadenum virginicum	0.1 4	0.1 -	0.1 *	0.0	0.0 -	0.1 -	0.1	<0.1	0.1	<0.1	0.4591	<0.0001
Websteria sp.	0.1 4	0.0 -	0.2 *	0.0 -	0.0 -	0.0 -	0.0	0.1	0.0	0.1	0.1799	b
Xyris sp.	893.7 77957	611.7	1586.4 *	1027.5	677.4	255.4 -	1336.4	466.6	833.3	973.2	0.2504	0.3311
Mean Sample Species Diversity		1.0	0.7	0.6	0.7	0.7	0.8	0.7	0.8	0.7	0.1969	0.4668
Mean Sample Species Richness		4.8	4.8	4.2	3.8	3.6	5.1	3.5	4.3	4.4	0.7336	0.0171
Mean Total Seedling Count per m^2	1229.5	979.3 [c]	2023.2	1267.4	827.2	761.8	122.8	41.9	76.5	88.3	0.1607	0.3104

[a] Species that are dominant in (*) or absent from (-) the standing vegetation in the area are so indicated.
[b] All values are the same for one of the seasons, so the variance test was not calculated.
[c] Reported densities were calculated using totals from each area (Chesser Prairie, Durdin Prairie, Floyd's Prairie, Sapling Prairie, Sill Area), not over all samples combined from throughout the swamp. For treatment and season, densities were calculated using totals from all samples collected throughout the swamp.

Table 7-2. Vegetation species absent from the Okefenokee Swamp seed bank samples, but present in plots of established vegetation.

Species	Area Where Species is Most Abundant in Standing Vegetation Along Sample Transects	Areas Where Species is Absent from Standing Vegetation Along Sample Transects
Acer rubrum	Sill Area	Chesser, Durdin, Sapling Prairies
Brasenia schreberi	Durdin Prairie	Chesser, Floyd's, Sapling Prairies, Sill Area
Calapogon sp.	Durdin Prairie	Chesser, Floyd's, Sapling Prairies, Sill Area
Carex glomeratus	Sill Area	Chesser, Floyd's, Sapling Durdin Prairies
Cephalanthus occidentalis	Sill Area	Chesser, Durdin, Sapling Prairies
Cliftonia monophylla	Durdin Prairie	Chesser, Floyd's, Sapling Prairies, Sill Area
Fraxinus caroliniana	Sill Area	Chesser, Floyd's, Sapling Durdin Prairies
Ilex coriacea	Durdin Prairie	Chesser, Floyd's, sapling Prairies, Sill Area
Ilex myrtifolia	Sill Area	Chesser, Durdin, Sapling, Floyd's Prairies
Lyonia lugustrina	Sill Area	Chesser, Floyd's, Sapling Durdin Prairies
Magnolia virginiana	Sill Area	Chesser, Durdin, Sapling Prairies
Myrica cerifera	Durdin Prairie	Chesser, Floyd's, Sapling Prairies, Sill Area
Nyssa ogeechee	Sill Area	Chesser, Floyd's, Sapling Durdin Prairies

Species	Area Where Species is Most Abundant in Standing Vegetation Along Sample Transects	Areas Where Species is Absent from Standing Vegetation Along Sample Transects
Pierus phillyreifolia	Floyd's Prairie	Chesser Prairie
Pinus elliottii	Durdin Prairie	Chesser, Floyd's, Sapling Prairies, Sill Area
Rhynchospora chalerocephala	Durdin Prairie	Sapling Prairie, Sill Area
Vaccinium corymbosum	Chesser Prairie	Durdin, Floyd's, Sapling Prairies
Woodwardia virginica	Chesser Prairie	in all areas

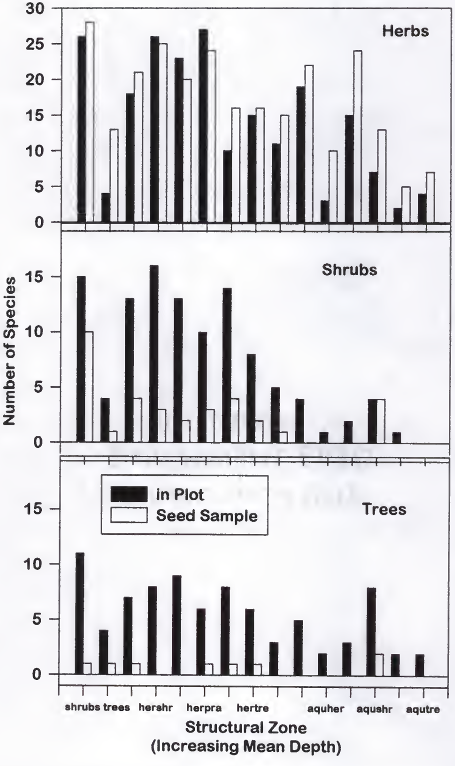


Figure 7-3. Counts of species and germinated seeds in seed bank samples, compared to species counts in the standing vegetation within the structural zone at the collection site. Structural zones are described in Table 6-1.

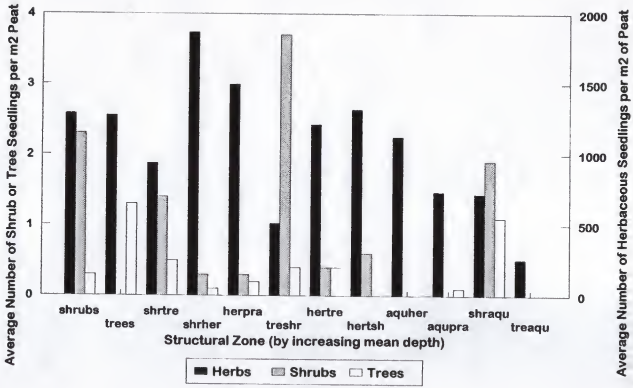


Figure 7-3--continued.

Table 7-3. Average number of species in the established vegetation and in the seed bank from structural zones throughout Okefenokee Swamp.

Area, Zone Type, and Sample Size	Average and Range of # Species in Established Vegetation	Average and Range of # Species in Seed Bank	Average and Range of # Species in Established Vegetation *and also* in Seed Bank
Chesser Prairie			
aquatic-herbaceous prairie (6)	5.5 (3-10)	10.8 (9-15)	3.0 (1-6)
aquatic prairie (8)	4.1 (3-6)	9.4 (4-13)	2.3 (2-5)
herbaceous prairie (8)	8.4 (3-14)	13.5 (10-17)	4.0 (2-6)
shrubs-herbaceous prairie (8)	8.5 (4-13)	12.6 (8-16)	3.6 (2-6)
shrubs (6)	8.8 (5-14)	12.3 (9-14)	3.3 (0-7)
Durdin Prairie			
aquatic-herbaceous prairie (6)	6.8 (4-9)	11.5 (7-16)	4.2 (2-6)
aquatic prairie (3)	5.3 (5-6)	8.3 (7-11)	2.7 (2-3)
herbaceous prairie (10)	13.0 (7-17)	14.8 (12-18)	6.7 (4-10)
shrubs-herbaceous prairie (13)	16.1 (7-24)	14.0 (11-18)	7.2 (3-11)
shrubs-trees (1)	22.0	15.0	8.0
shrubs (6)	16.8 (11-21)	15.3 (12-21)	6.5 (4-9)

Area, Zone Type, and Sample Size	Average and Range of # Species in Established Vegetation	Average and Range of # Species in Seed Bank	Average and Range of # Species in Established Vegetation ***and also*** in Seed Bank
Floyd's Prairie			
aquatic-herbaceous prairie (5)	4.6 (3-7)	11.6 (10-14)	3.4 (3-4)
aquatic prairie (5)	4.6 (3-8)	10.0 (7-12)	3.2 (2-4)
herbaceous prairie (2)	8.0 (7-9)	11.0 (8-14)	3.0 (2-4)
herbaceous prairie-trees (4)	7.8 (5-10)	10.8 (9-13)	2.8 (2-4)
herbaceous prairie-trees-shrubs (2)	10.0 (9-11)	12.5 (11-14)	4.0 (4)
shrubs-herbaceous prairie (9)	10.1 (6-14)	10.2 (7-13)	3.1 (1-5)
shrubs-trees (3)	11.3 (10-12)	8.7 (6-12)	2.7 (2-4)
shrubs (4)	12.0 (10-14)	10.0 (9-12)	2.5 (2-3)
trees-shrubs (1)	15.0	16.0	6.0
Sapling Prairie			
aquatic-herbaceous prairie (1)	7.0	9.0	3.0
aquatic prairie (6)	5.2 (4-7)	9.7 (7-11)	3.5 (3-4)
herbaceous prairie (10)	7.0 (5-10)	11.9 (9-15)	4.3 (2-7)

Area, Zone Type, and Sample Size	Average and Range of # Species in Established Vegetation	Average and Range of # Species in Seed Bank	Average and Range of # Species in Established Vegetation *and also* in Seed Bank
herbaceous prairie-trees (1)	10.0	12.0	5.0
herbaceous prairie-trees-shrubs (1)	11.0	12.0	7.0
shrubs-herbaceous prairie (7)	9.1 (5-11)	11.1 (8-15)	4.3 (2-6)
shrubs-trees (4)	9.8 (8-11)	12.5 (9-17)	2.0 (1-4)
shrubs (3)	9.7 (7-13)	10.3 (8-15)	2.7 (1-4)
Sill Area			
aquatic prairie (5)	4.4 (2-6)	8.4 (5-11)	2.4 (2-3)
shrubs-aquatic prairie (5)	6.6 (4-10)	10.2 (7-12)	3.8 (3-5)
shrubs-herbaceous prairie (1)	8.0	11.0	3.0
shrubs (3)	7.3 (5-10)	9.7 (9-11)	3.0 (3)
trees-aquatic prairie (2)	5.0 (4-6)	8.0 (7-9)	3.0 (2-4)
trees (3)	5.7 (4-7)	8.3 (7-10)	2.3 (1-4)
trees-shrubs (4)	8.3 (7-9)	9.8 (6-13)	3.0 (2-4)

Table 7-4. Modeled parameters and their significance in predicting responses of seed bank species to area, structural zone type, and treatment.

Species or Hydrologic Zone Type	Season (Autumn or Spring)	Area P > F	Structural Zone P > F	Area x Structural Zone P > F	Treatment (Exposed, Submerged) P > F	Greatest Treatment Response, Exposed vs. Submerged	Area x Treatment P > F	Treatment x Structural Zone P > F	Model P > F, R^2	Structural Zones with Highest Seedling Densities [b]	Structural Zones with Lowest Seedling Densities	Structural Zones Where Species Absent in Both Seasons	Area Trend, Highest to Lowest Seedling Densities [c]
Species [a]													
Carex walteriana	Autumn	0.0259			0.0001	Exposed		0.0001	0.0845 0.4725	hertsh	aqupra	shraqu, treaqu, trees	F/D/Sp>C>S
	Spring	0.0453			0.1047	Exposed			0.3258 0.4417	hertre	aqupra, shrtre, shrubs		D/F>Sp/C>S
Andropogon sp./ *Erianthus* sp.	Autumn	0.0165			0.0010	Exposed	0.0002		0.0001 0.6025	shrher	aqupra	hertsh, treaqu, shraqu, trees	D>F>C>S>Sp
	Spring	0.0169			0.0087	Exposed	0.0001		0.0001 0.5858	herpra	aqupra, hertre, shrtre		D>F>Sp>C>S
Dulichium arendinaceum	Autumn	0.0671	0.0016	0.0300	0.0001	Exposed	0.0307		0.0001 0.7693	treaqu	aqupra	in all zones	C>S>D>F>Sp
	Spring		0.0091		0.0001	Exposed	0.0321	0.0026	0.0001 0.7322	treaqu	aqupra		C>D>S>F>Sp
Drosera intermedia	Autumn	0.0011	0.0054	0.1275	0.0001	Exposed	0.0001	0.0422	0.0001 0.6720	shrtre	aqupra	shraqu, trees, treaqu, treshr	Sp>D>C>F>S
	Spring	0.011	0.0272	0.0059	0.0001	Exposed	0.0012		0.0001 0.6356	shrtre	aqupra		Sp>D>C>F>S
Eleocharis baldwinii/ vivipara	Autumn	0.0234			0 0001	Exposed	0.0059		0.0001 0.5777	trees, shraqu	shrtre	in all zones	S>C>F>Sp>D
	Spring	0.0150	0.0671		0.0001	Exposed	0.0013		0.0001 0.7331	shraqu	shrtre		S>C>D>Sp/F
Eleocharis robbinsii	Autumn	0.0024	0.0017		0.0001	Exposed	0.0210	0.0406	0.6567 0.4217	aqupra	shrtre	treaqu,trees, treshr	F>Sp>C>D>S

Table 7-4--continued.

Species or Hydrologic Zone Type	Season (Autumn or Spring)	Area P > F	Structural Zone P > F	Area x Structural Zone P > F	Treatment (Exposed, Submerged) P > F	Greatest Treatment Response, Exposed vs. Submerged	Area x Treatment P > F	Treatment x Structural Zone P > F	Model P > F, R^2	Structural Zones with Highest Seedling Densities[b]	Structural Zones with Lowest Seedling Densities	Structural Zones Where Species Absent in Both Seasons	Area Trend, Highest to Lowest Seedling Densities[c]
	Spring	0.0002	0.0001		0.0002	Exposed		0.0865	0.0001 0.7064	aqupra	shraqu		Sp>F>C>D>S
Syngonanthus sp./ *Eriocaulon* sp.	Autumn	0.0004			0.0001	Exposed	0.0001		0.0001 0.6395	herpra	hertre	hertsh, treaqu, trees	D>C>Sp>F>S
	Spring	0.0735			0.1186	Exposed	0.1242		0.4431 0.3604	herprs/ shrher	treshr		D>C>Sp>F>S
Lacnanthes caroliniana	Autumn	0.0041			0.0001	Exposed	0.0001	0.1391	0.0001 0.7831	shrher	shraqu	trees	F>C/D>Sp/S
	Spring	0.0272	0.0414		0.0001	Exposed	0.0051	0.1201	0.0001 0.8008	shrher	shraqu		F/C>D>Sp>S
Ludwigia alata	Autumn		0.0123	0.0292	0.0001	Exposed	0.0113		0.0001 0.7201	hertre	aqupra	treaqu	F>C/S>Sp>D
	Spring	0.0004	0.0040	0.0488	0.0001	Exposed	0.0001	0.0160	0.0001 0.7402	hertre	aqupra, trees		F>C>S>Sp>D
Nuphar luteum	Autumn	0.0003			0.0001	Submerged	0.0001		0.0001 0.5622	treaqu	herpra, shrher, aquher	hertre, hertsh, shrtre	S>D>Sp>F>C
	Spring	0.1306	0.1129		0.0017	Submerged	0.0298	0.0371	0.0001 0.5259	aqupra, shraqu	shrher, treaqu, trees		S>Sp/D>C>F
Nymphaea odorata	Autumn	0.0138	0.0001		0.0011	Submerged	0.1066		0.0001 0.7999	aquher, shraqu, aqupra	shrtre, treaqu	in all zones	D>S>C>F>Sp
	Spring	0.0004	0.0001		0.0001	Submerged			0.0001 0.7864	aquher, aqupra, shraqu	treaqu, treshr		D>C/S>F>Sp
Panicum hemitomon	Autumn		0.0001		0.0001	Exposed	0.0065	0.0783	0.0001 0.8343	trees, treshr	herpra, shrher, hertsh	hertre	S>Sp/C>F>D

Table 7-4--continued.

Species or Hydrologic Zone Type	Season (Autumn or Spring)	Area P > F	Structural Zone P > F	Area x Structural Zone P > F	Treatment (Exposed, Submerged) P > F	Greatest Treatment Response, Exposed vs. Submerged	Area x Treatment P > F	Treatment x Structural Zone P > F	Model P > F, R^2	Structural Zones with Highest Seedling Densities [b]	Structural Zones with Lowest Seedling Densities	Structural Zones Where Species Absent in Both Seasons	Area Trend, Highest to Lowest Seedling Densities [c]
	Spring		0.0205	0.0725	0.0012	Exposed			0.0001 0.7846	trees, treshr	aqupra, herpra, shrher		S>F/Sp>C>D
Rhynchospora fascicularis	Autumn	0.0015	0.0087		0.0001	Exposed	0.0001	0.0067	0.0001 0.6110	shrubs	aqupra	shraqu, treaqu, trees	D>C>Sp>F/S
	Spring	0.0119	0.0382		0.0003	Exposed	0.0075	0.0740	0.0001 0.6884	shrubs, shrher	aqupra, treshr, hertre		D>C>Sp>F/S
Rhynchospora inundata	Autumn	0.0001	0.0078	0.0013	0.0001	Exposed	0.0001	0.0829	0.0001 0.6276	aquher, aqupra, hertre	shrubs, shrtre, treshr	shraqu, trees	C/F>Sp>D>S
	Spring	0.0001	0.0001	0.0001	0.0001	Exposed	0.0171		0.0001 0.7912	aquher, aqupra, hertsh	shrubs, treaqu, treshr		F>C/Sp>D>S
Syngonanthus flavidulus	Autumn				0.0196	Exposed			0.9756 0.3762	shrubs	aquher, aqupra	hertre, hertsh, shraqu, treaqu, trees, treshr	D>C/Sp>F/S
	Spring	0.0009	0.0907		0.0004	Exposed	0.0006		0.0001 0.6131	shrubs shrher	aquher, aqupra		D>C/Sp>F/S
Xyris sp.	Autumn	0.0050	0.0041	0.0027	0.0001	Exposed	0.0064		0.0001 0.8007	hertsh, shrher, hertre	treaqu	in all zones	F/D>C/Sp>S
	Spring	0.0429	0.0001	0.0001	0.0001	Exposed	0.0151		0.0001 0.8336	hertsh	treaqu		F>D>Sp>C>S
Juncus repens	Autumn				0.0003	Exposed		0.0107	0.0001 0.8336	trees, shraqu	aqupra, shrubs	aquher, herpra, hertre, hertsh, shrher, shrtre, treaqu, treshr	in Sill Area only
	Spring		0.0134		0.0001	Exposed		0.0047	0.0001 0.9294	trees, shraqu	aqupra, shrubs		in Sill Area only

Table 7-4--continued.

Species or Hydrologic Zone Type	Season (Autumn or Spring)	Area P > F	Structural Zone P > F	Area x Structural Zone P > F	Treatment (Exposed, Submerged) P > F	Greatest Treatment Response, Exposed vs. Submerged	Area x Treatment P > F	Treatment x Structural Zone P > F	Model P > F, R^2	Structural Zones with Highest Seedling Densities [b]	Structural Zones with Lowest Seedling Densities	Structural Zones Where Species Absent in Both Seasons	Area Trend, Highest to Lowest Seedling Densities [c]
Species Diversity	Autumn	0.0010	0.1375		0.0001	Exposed	0.0524		0.0001 0.6555	treaqu, shraqu, aqupra, trees	hertre, hertsh, shrtre	in all zones	C>S>D/Sp>F
	Spring	0.0002	0.0266	0.0074	0.0001	Exposed		0.0001	0.0001 0.6981	aquher, aqupra, herpra, shraqu	hertre, hertsh, treaqu, trees, treshr		C>D/F/Sp/S
Species Richness	Autumn	0.0994			0.0001	Exposed		0.0159	0.0001 0.7470	shrher, herpra, shrubs, shraqu	herpra, shrher, aquher	in all zones	C/D>S/F>Sp
	Spring			0.0817	0.0001	Exposed		0.0001	0.0001 0.7030	shrtre, treaqu	treaqu		C/D>F>Sp>S
Total Seedlings	Autumn	0.0014		0.1486	0.0001	Exposed			0.0001 0.8220	shrher, herpra, aquher	treshr, treaqu	in all zones	D/F>Sp/C>S
	Spring	0.0630	0.0290	0.0032	0.0001	Exposed		0.0014	0.0001 0.8128	shrher, hertsh, hertre, herpra	treaqu, treshr		D/F>Sp/C>S
Hydrologic Zone Type													
Constant, Deep Water	Autumn	0.0010			0.0001	Exposed	0.0003		0.0001 0.7356	no trend	no trend	in all structural zones	D>C/Sp>F>S
	Spring	0.0001			0.0001	Exposed	0.0001		0.0001 0.7323	no trend	no trend		D>Sp>C/F>S
Moderately Variable, Deep Water	Autumn	0.0077	0.0001	0.0013	0.0001	Exposed		0.0129	0.0001 0.7897	aquher	treaqu	in all structural zones	D>F>C>S>Sp

Table 7-4--continued.

Species or Hydrologic Zone Type	Season (Autumn or Spring)	Area P > F	Structural Zone P > F	Area x Structural Zone P > F	Treatment (Exposed, Submerged) P > F	Greatest Treatment Response, Exposed vs. Submerged	Area x Treatment P > F	Treatment x Structural Zone P > F	Model P > F, R^2	Structural Zones with Highest Seedling Densities[b]	Structural Zones with Lowest Seedling Densities	Structural Zones Where Species Absent in Both Seasons	Area Trend, Highest to Lowest Seedling Densities[c]
	Spring	0.0516	0.0001	0.0001	0.0001	Exposed		0.0025	0.0001 0.7719	aquher	treaqu		D/F>C/Sp>S
Variable, Deep Water	Autumn	0.0409	0.0012	0.0138	0.0001	Exposed	0.0481	0.0443	0.0001 0.7640	treaqu, trees, treshr, shrher	hertsh, aquher, aqupra, hertre	in all structural zones	S>C>D>F/Sp
	Spring	0.1144	0.0088		0.0001	Exposed	0.0336	0.0019	0.0001 0.7143	treaqu, shrubs	aqupra, hertsh		C>D>S>Sp>F
Constant, Moderately Deep Water	Autumn					no significant effect			0.0001 0.1328	no trend	no trend	hertsh, shraqu, treaqu	C/D>F>Sp>S
	Spring	0.0844				no significant effect			0.0001 0.1885	no trend	no trend		D>C>F>Sp>S
Moderately Variable, Moderate Water Depth	Autumn	0.0234			0.0001	Exposed	0.0278		0.0001 0.5777	trees, shraqu, aqupra	shrtre	in all structural zones	S>C>F/Sp>D
	Spring	0.0150	0.0671		0.0003	Exposed	0.0260	0.0059	0.0001 0.7331	shraqu	shrtre, aquher		S>C>D>F/Sp
Constant, Shallow Water	Autumn		0.0813			Exposed			0.0001 0.2715	shraqu	hertre, hertsh, treshr	treaqu	no area trend
	Spring				0.0160	Exposed			0.1515 0.0928	hertsh	shrher, trees, treshr		no area trend
Moderately Variable, Shallow Water	Autumn	0.0920	0.0421		0.0001	Exposed	0.0003	0.0202	0.0001 0.7706	shrher, shrubs	trees	in all structural zones	D/F>C>Sp>S
	Spring	0.1176	0.0184		0.0001	Exposed	0.0323	0.0294	0.0001 0.7929	shrher, shrubs, herpra	trees		C/D>F>Sp>S

Table 7-4--continued.

[a] Only most commonly occurring species are modeled, and $P > F$ are reported only for those < 0.15.
[b] Structural zone types represent segments of successional changes where seed bank samples were collected. They are abbreviated as follows: aqupra (aquatic prairie), aquher (aquatic herbaceous prairie), aqutre (aquatic prairie-trees), aqushr (aquatic prairie-shrubs), herpra (herbaceous prairie), hershr (herbaceous prairie-shrubs), hertre (herbaceous prairie-trees), hertsh (herbaceous prairie-trees-shrubs), treshr (trees-shrubs), shrubs, and trees.
[c] Areas are abbreviated as: C (Chesser Prairie), D (Durdin Prairie), F (Floyd's Prairie), Sp (Sapling Prairie), and S (Sill Area).

(Table 7-4). Lowest diversity occurred in Floyd's Prairie samples in the autumn and Floyd's and Sapling Prairies samples and the Sill area samples in the spring. Chesser Prairie samples consistently had the highest diversity of species, whereas Durdin and Floyd's Prairies samples had the greatest number of germinated seeds. The high germination rates in samples from these areas were due primarily to the abundance of yellow-eyed grass, water lily (*Nymphaea odorata*), and beakrush (*Rhynchospora inundata*) in Durdin Prairie samples, in addition to redroot (*Lacnanthes caroliniana*) in Floyd's Prairie samples. Species numbers per sample were more variable in the autumn than in the spring, although overall means did not differ (Table 7-1). Total counts and species diversity were greater for the exposed treatment, whereas species diversity was more variable among samples in submerged treatments (Table 7-1).

Trends in Response to Hydrologic Conditions

Responses of seed bank seedlings to gradients of water depths mirror those of the standing vegetation (see Chapter 6). Species in the seed bank could be loosely grouped into associations identified in Chapter 6, based on a general gradient of average water depth and variability (Table 7-5). Along this gradient, species in the seed bank that were found as standing vegetation in constant, deep water conditions (see Chapter 6) were less variable in numbers in the spring than in the autumn (Table 7-6). Many of these species (e.g., broomsedge, *Andropogon virginiana*; creeping rush, *Juncus repens*; bamboo greenbriar, *Smilax laurifolia*; Walter's greenbriar, S. walteri; red root; spikerush, *Eleocharis robbinsii*; dahoon holly, *Ilex cassine*) are autumn seed producers, which

Table 7-5. Hydrologic environments where seed bank species are found in Okefenokee Swamp, and areas of maximum species abundances in seed bank samples and established vegetation.

Species	Area Where Greatest Abundance Occurs in Seed Bank	Area Where Greatest Abundance Occurs in Established Vegetation	Hydrologic Zone Type Where Most Frequently Found in Established Vegetation	Structural Zone Type Where Most Frequently Found in Seed Bank
Andropogon sp./ *Erianthus* sp.	Durdin Prairie	Durdin Prairie	constant, deep	shrubs-herbaceous prairie
Bidens mitis	Durdin Prairie	Durdin Prairie	constant, moderately deep	shrubs-herbaceous prairie
Carex walteriana	Floyd's Prairie	Floyd's, Sapling Prairies	moderately variable, deep	herbaceous prairie-trees-shrubs
Clethra alnifolia	Sill Area	Floyd's Prairie	moderately variable, deep	shrubs
Cyperus erythrorhizos	Sill Area	Sill Area	moderately variable, deep	trees-shrubs
Cyrilla racemiflora	Sill Area	Chesser, Sapling Prairies	moderately variable, shallow	trees-shrubs
Decodon verticillatus	Sill Area	Durdin Prairie	moderately variable, deep	aquatic prairie-shrubs, trees-shrubs
Drosera intermedia	Sapling Prairie	Durdin Prairie	constant, deep	shrubs-trees
Dulichium arendinaceum	Chesser Prairie	Chesser Prairie	variable, deep	aquatic prairie-trees
Eleocharis baldwinii/vivipara	Sill Area	Sill Area	constant, moderately deep	trees
Eleocharis robbinsii	Floyd's Prairie	Floyd's Prairie	constant, deep	aquatic prairie
Erianthus giganteus	Durdin Prairie	Durdin Prairie	constant, deep	trees
Gordonia lasianthus	Sill Area	Chesser Prairie	constant, shallow	aquatic prairie-shrubs, herbaceous prairie-trees
Ilex cassine	Floyd's Prairie	Floyd's, Sapling Prairies	moderately variable, shallow	trees-shrubs
Iris virginiana	Chesser Prairie	Floyd's Prairie	constant, deep	herbaceous prairie-trees

Species	Area Where Greatest Abundance Occurs in Seed Bank	Area Where Greatest Abundance Occurs in Established Vegetation	Hydrologic Zone Type Where Most Frequently Found in Established Vegetation	Structural Zone Type Where Most Frequently Found in Seed Bank
Itea virginiana	Sill Area	Floyd's Prairie	variable, deep	shrubs
Juncus repens	Sill Area	Sill Area	moderately variable, deep	trees
Juncus triganocarpus	Sill Area	Sill Area	constant, shallow	aquatic prairie-shrubs
Lacnanthes caroliniana	Floyd's Prairie	Durdin Prairie	moderately variable, shallow	herbaceous prairie-shrubs
Leucothoe racemosa	Durdin Prairie	Sill Area	moderately variable, shallow	shrubs
Ludwigia alata	Floyd's Prairie	Sill Area	constant, deep	shrubs-trees
Lyonia lucida	Chesser Prairie	Chesser, Durdin Prairies	moderately variable, shallow	shrubs
Lyonia sp.	Sill Area		moderately variable, shallow	herbaceous prairie-trees
Nuphar luteum	Sill Area	Sill Area	variable, deep	aquatic prairie-trees
Nymphaea odorata	Durdin Prairie	Chesser Prairie	moderately variable, deep	aquatic prairie
Nyssa sylvatica v. *biflora*	Sill Area	Sill Area	variable, deep	aquatic prairie-shrubs
Orontium aquaticum	Floyd's, Sapling Prairies	Chesser Prairie	moderately variable, deep	aquatic prairie
Panicum hemitomon/ Sacciolepis striata	Sill Area	Sapling Prairie, Sill Area	moderately variable, deep	trees-shrubs
Rhynchospora alba	Durdin Prairie	Durdin Prairie	moderately variable, shallow	aquatic-herbaceous prairie
Rhynchospora cephalantha/ microcephala	Durdin Prairie	Floyd's Prairie	moderately variable, shallow	herbaceous prairie-shrubs
Rhynchospora fascicularis/ wrightiana	Durdin Prairie	Durdin Prairie	moderately variable, shallow	shrubs

Species	Area Where Greatest Abundance Occurs in Seed Bank	Area Where Greatest Abundance Occurs in Established Vegetation	Hydrologic Zone Type Where Most Frequently Found in Established Vegetation	Structural Zone Type Where Most Frequently Found in Seed Bank
Rhynchospora inundata	Floyd's Prairie	Durdin Prairie	moderately variable, deep	herbaceous prairie-trees
Rhynchospora spp.	Durdin Prairie	Durdin Prairie	moderately variable, shallow	herbaceous prairie-trees-shrubs
Saggetaria graminea	Chesser Prairie	Floyd's Prairie	constant, moderately deep	herbaceous prairie
Sarracenia flava	Durdin Prairie	Durdin Prairie	constant, moderately deep	shrubs-trees
Sarracenia psittacenia/flava	Durdin Prairie	Durdin Prairie	constant, moderately deep	shrubs
Scleria reticularis	Chesser Prairie	Chesser Prairie	constant, shallow	herbaceous prairie-trees-shrubs
Smilax laurifolia	Chesser, Durdin Prairies	Durdin Prairie	moderately variable, shallow	shrubs
Smilax walteri	Durdin Prairie	Floyd's Prairie	moderately variable, shallow	trees-shrubs
Smilax spp.	Chesser Prairie		moderately variable, shallow	herbaceous prairie
Syngonanthus sp./ *Ericaulon* sp.	Durdin Prairie	Durdin Prairie	constant, deep	shrubs-herbaceous prairie
Syngonanthus flavidulus	Durdin Prairie	Durdin Prairie	constant, deep	shrubs-herbaceous prairie
Taxodium ascendens	Sapling Prairie	Sapling Prairie	moderately variable, deep	herbaceous prairie
Triadenum virginicum	Chesser Prairie	Durdin Prairie	constant, moderately deep	trees
Websteria sp.	Durdin Prairie	Durdin Prairie	constant, deep	aquatic prairie
Xyris sp.	Durdin Prairie	Durdin Prairie	moderately variable, deep	shrubs-herbaceous prairie

Table 7-6. Effects of season on response of seed bank samples (counts) collected from hydrologic zone types and areas of Okefenokee Swamp.

Hydrologic Zone Type or Area	**Seasonal Variances Differ, P > F**	**Season with Larger Variance**	**Seasonal Means Differ, P > t**	**Season with Larger Mean**
Constant, Deep Water	Yes <0.0001	Autumn	No	
Constant, Moderately Deep Water	No		No	
Moderately Variable, Deep Water	No		No	
Variable, Deep Water	Yes <0.0001	Autumn	Yes 0.0001	Autumn
Moderately Variable, Moderately Deep Water	Yes 0.0021	Autumn	Yes 0.0001	Autumn
Constant, Shallow Water	Yes <0.0001	Autumn	No	

probably contributed to this trend (Table 7-7). Differences, by structural zone, in seedling numbers were not significant in this species' group, although treatment responses differed (Table 7-4). Highest germination occurred in exposed treatments (Table 7-4). As water depths decreased but variability remained constant, structural zone differences continued to be non-significant, which probably relates to wind as the predominant dispersal method of these species (Table 7-7). Differences between treatments declined along this gradient of water depth. With gradually decreasing water depths, variability in seedling counts continued to be higher in the autumn (Table 7-6). The low variability in water levels where these species occur across the depth gradient, and the ability of many of these species (e.g., broomsedge, redroot, yellow-eyed grass, spikerush) to germinate in exposed and submerged conditions, suggests generalist habits that result in high seed and seedling survival of these primarily wind-dispersed species throughout a broad range of water depths.

Species in the seed bank that were found as standing vegetation in more variable water depth conditions (see Chapter 6) showed more pronounced seasonal changes in abundance and variability in the seed bank as water depths and variability increased (Table 7-4). Differences in seed bank composition among structural zone types were also more apparent in these species (Table 7-3). Structural zones with the lowest density of germinated seeds could be grouped into 2 types. Aquatic and herbaceous prairie structural zone types generally occurred where water levels were fairly constant; therefore, abundances of species found more often in variable environments were not expected in these structural zones, as illustrated in Table 7-3. Samples from structural

Table 7-7. Germination and dispersal characteristics of Okefenokee Swamp seed bank species, summarized from field observation, seed bank samples, Porcher (1995), and Conti and Gunther (1984).

Species	Persistent (>1 year) or Transient (<1 year) in Seed Bank	Sampling Areas Where Present in Seed Bank	Initial Dispersal Season	Seed Size	Primary Mode of Dispersal	Structural Zone Type Where Most Frequently Found in Seed Bank
Andropogon sp./ *Erianthus* sp.	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	autumn	small	wind	shrubs-herbaceous prairie
Bidens mitis	persistent	Durdin, Floyd's, Sill	late summer	medium	water	shrubs-herbaceous prairie
Carex walteriana	transient	Chesser, Durdin, Floyd's, Sapling, Sill	summer	medium	water	herbaceous prairie-trees-shrubs
Clethra alnifolia	transient	Sill	late summer	small	wind/water	shrubs
Cyperus erythrorhizos	persistent	Chesser, Durdin, Floyd's, Sill	autumn	medium	water	trees-shrubs
Cyrilla racemiflora	transient	Chesser, Durdin, Floyd's, Sapling, Sill	late summer	medium	water	trees-shrubs
Decodon verticillatus	transient	Sill	late summer	small	wind/water	aquatic prairie-shrubs, trees-shrubs
Drosera intermedia	transient	Chesser, Durdin, Floyd's, Sapling	early summer	small	water	shrubs-trees
Dulichium arendinaceum	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	late summer	small	water	aquatic prairie-trees
Eleocharis baldwinii/vivipara	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	summer	small	water	trees

Table 7-7--continued.

Species	Persistent (>1 year) or Transient (<1 year) in Seed Bank	Sampling Areas Where Present in Seed Bank	Initial Dispersal Season	Seed Size	Primary Mode of Dispersal	Structural Zone Type Where Most Frequently Found in Seed Bank
Eleocharis robbinsii	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	autumn	small	wind/water	aquatic prairie
Erianthus giganteus	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	autumn	small	wind	trees
Gordonia lasianthus	transient	Sapling, Sill	late summer	small	wind	aquatic prairie-shrubs, herbaceous prairie-trees
Ilex cassine	transient	Floyd's	autumn	large	water	trees-shrubs
Iris virginiana	transient	Chesser, Floyd's	early summer	small	water	herbaceous prairie-trees
Itea virginiana	transient	Sill	late summer	small	wind/water	shrubs
Juncus repens	persistent	Sill	autumn	small	water	trees
Juncus triganocarpus	persistent	Chesser , Sill	summer	small	water	aquatic prairie-shrubs
Lacnanthes caroliniana	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	autumn	small	wind/water	herbaceous prairie-shrubs
Leucothoe racemosa	transient	Chesser, Durdin, Floyd's, Sapling	summer	small	wind/water	shrubs
Ludwigia alata	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	early autumn	medium	water	shrubs-trees

Table 7-7--continued.

Species	Persistent (>1 year) or Transient (<1 year) in Seed Bank	Sampling Areas Where Present in Seed Bank	Initial Dispersal Season	Seed Size	Primary Mode of Dispersal	Structural Zone Type Where Most Frequently Found in Seed Bank
Lyonia lucida	transient	Chesser, Durdin, Floyd's, Sapling, Sill	summer	small	wind/water	shrubs
Lyonia sp.	transient	Chesser, Sapling, Sill	summer	small	wind/water	herbaceous prairie-trees
Nuphar luteum	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	summer	large	water	aquatic prairie-trees
Nymphaea odorata	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	summer	large	water	aquatic prairie
Nyssa sylvatica v. *biflora*	transient	Sill	autumn	large	water	aquatic prairie-shrubs
Orontium aquaticum	transient	Floyd's, Sapling	summer	large	water	aquatic prairie
Panicum hemitomon/ Sacciolepis striata	persistent	Chesser, Floyd's, Sapling, Sill	summer	small	wind/water	trees-shrubs
Rhynchospora alba	persistent	Chesser, Durdin	summer	small	wind/water	aquatic-herbaceous prairie
Rhynchospora cephalantha/ microcephala	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	summer	small	wind/water	herbaceous prairie-shrubs

Table 7-7--continued.

Species	Persistent (>1 year) or Transient (<1 year) in Seed Bank	Sampling Areas Where Present in Seed Bank	Initial Dispersal Season	Seed Size	Primary Mode of Dispersal	Structural Zone Type Where Most Frequently Found in Seed Bank
Rhynchospora fascicularis/ wrightiana	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	summer	small	wind/water	shrubs
Rhynchospora inundata	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	summer	medium	water	herbaceous prairie-trees
Rhynchospora sp.	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	summer	medium	wind/water	herbaceous prairie-trees-shrubs
Sagettaria graminea	persistent	Chesser, Durdin, Floyd's, Sapling	summer	small	water	herbaceous prairie
Sarracenia flava	persistent	Durdin	summer	small	water	shrubs-trees
Sarracenia psittacenia/flava	persistent	Durdin	summer	small	water	shrubs
Scleria reticularis	persistent	Sapling, Sill	summer	medium	water	herbaceous prairie-trees-shrubs
Smilax laurifolia	transient	Chesser, Durdin, Sapling, Sill	autumn	large	water	shrubs
Smilax walteri	transient	Chesser, Durdin, Floyd's, Sill	autumn	large	water	trees-shrubs
Smilax spp.	transient	Chesser, Durdin, Sapling	autumn	large	water	herbaceous prairie
Syngonanthus sp./ *Ericaulon* sp.	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	early summer	small	water	shrubs-herbaceous prairie

Table 7-7--continued.

Species	Persistent (>1 year) or Transient (<1 year) in Seed Bank	Sampling Areas Where Present in Seed Bank	Initial Dispersal Season	Seed Size	Primary Mode of Dispersal	Structural Zone Type Where Most Frequently Found in Seed Bank
Syngonanthus flavidulus	persistent	Chesser, Durdin, Floyd's, Sapling	early summer	small	water	shrubs-herbaceous prairie
Taxodium ascendens	transient	Sapling	late autumn-spring	large	water	herbaceous prairie
Triadenum virginicum	persistent	Chesser, Durdin, Sill	summer	small	water	trees
Websteria sp.	persistent	Durdin	summer	small	water	aquatic prairie
Xyris sp.	persistent	Chesser, Durdin, Floyd's, Sapling, Sill	late summer	small	wind	shrubs-herbaceous prairie

types of shrubs-trees, trees, and aquatic (or deep water)-trees structural zone types also had low numbers of germinated seeds (Table 7-3). Although these zones may be found where water levels are more variable (e.g., the trees and aquatic-trees zone types were found only in the sill area) and would therefore be expected to have greater numbers of species that are found in the standing vegetation of hydrologically variable environments, these zones had sparse seed banks. The herbaceous understory cover was not dense in these areas, most likely due to dense shrub and tree growth, and deep water levels in the sill area. Therefore the contribution of herbaceous species to the seed bank of these structural zones was small. However, herbaceous species in the standing vegetation that were more abundant where water level variability was greater, were also more abundant in the seed bank of these zone types (Table 7-3).

Treatment type also significantly affected the germination response of species that most frequently occur under variable hydrologic conditions (Table 7-4). Many of these species, particularly woody species that germinated from the sill area seed bank samples collected in the spring, disperse their seeds in the autumn and early winter; survival of these seeds is probably enhanced if water levels are at their annual low levels when this seed rain occurs. Later, rising water levels due to increasing late-winter precipitation transport seeds away from the parent plants, possibly distributing them to suitable germination sites.

Seed bank and standing vegetation compositions were most similar where vegetation structure was most complex (Table 7-3). Shrubs-aquatic prairie, herbaceous prairie, shrubs, shrubs-herbaceous prairie, and herbaceous prairie-trees-shrubs had the

greatest similarities between the seed pools and established vegetation, and the latter 3 zones had the greatest species richness in the seed bank and established vegetation. These structural zone types also corresponded generally to areas of relatively constant water depths, which is reflected in the list of dominant species in the zones (Table 7-5).

Discussion

Wetland Seed Bank Composition and Vegetation Community Dynamics

Wetland seed banks provide clues to historic vegetation (Leck 1989), suggest current species dynamics and departures from historic conditions in the environment, and indicate potential responses to future environmental variability and disturbances. Importance of the seed bank in wetland dynamics varies with individual wetland and wetland type, although similar trends in seed bank contents and structure among wetlands reflect similar environmental dynamics and their effects. Thompson and Grime (1979) identified 4 seed bank strategies that result in seed bank temporal and spatial variability (Type I: transient summer and autumn colonizers; Type II: transient winter and spring colonizers; Type III: persistent or transient; Type IV: persistent). Species representing all of these germination strategies were present in a range of densities in the sampled Okefenokee Swamp seed banks (Table 7-7), indicating that a variety of responses in seed germination and the established vegetation community that develops is possible with environmental variability.

Transient species, which persist in the seed bank for less than a year after dehiscence, are mostly summer and autumn annual and perennial grasses that colonize dry or disturbed habitats (Type I), and Type II species or annual and perennial herbs and woody species that colonize gaps in late winter and early spring (Thompson and Grime 1979). Seeds of these species are usually large, readily germinate in light or dark conditions, and are generally found near the soil surface (Leck 1989, Thompson and Grime 1979). This type is represented by cypress, blackgum (*Nyssa sylvatica* v. *biflora*), red maple (*Acer rubrum*), loblolly bay (*Gordonia lasianthus*), sweet bay (*Magnolia virginiana*), swamp red bay (*Persea palustris*), titi, fetterbush (*Leucothoe racemosa*), hurrahbush (*Lyonia lucida*), Walter's greenbriar (*Smilax walteri*), and bamboo greenbriar (*S. laurifolia*) and other shrubs and trees in Okefenokee Swamp. Transient herbaceous species in the swamp include arum (*Peltandra virginica*), spatterdock (*Nuphar luteum*), waterlily, goldenclub (*Orontium aquaticum*), blue flag iris (*Iris virginiana*) , and narrow leaf sagittaria (*Sagittaria graminea*). Persistent species, which remain viable in the seed bank for >1 year, may have a transient component in the seed bank (Type III) or are completely persistent with a large sub-surface reserve (Type IV) (Thompson and Grime 1979). These species are usually small-seeded, and require light, alternating temperatures, and aerobic conditions to stimulate germination (Leck 1989, Thompson and Grime 1979). Approximately 95% of the seeds collected from the Okefenokee Swamp seed pool and germinated in exposed or inundated conditions represent the persistent component.

Just as seed bank composition can affect standing vegetation composition with changes in the site environment, seasonal and annual dynamics of the standing vegetation affected by disturbance (e.g., fire, scouring by flooding, animal activity), disease, and hydrologic cycles can significantly affect seed bank composition (Leck 1989). Thus the diversity, size, and composition of the seed bank may provide clues to a wetland's disturbance, hydrologic, and succession history (Leck 1989). In some wetlands fire is an important influence on seed dynamics, whereas it has a minimal effect in others (Smith and Kadlec 1985). Light and nutrient availability and moisture conditions are drastically altered by peat and surface fires, and response of the vegetation community to these changes may be rapid. The seed bank probably plays an integral role in post-fire vegetation dynamics of non-woody species in Okefenokee Swamp. Cypert (1973, 1961) found that within a few years after fire woody species in Okefenokee Swamp were recovering from burn damage predominantly through coppice growth and stump sprouting, and except where burns removed peat and killed root systems, composition of woody species was approaching that before the burn. Cypert made no tally of seed-sprouting woody species; regrowth was primarily through stump sprouting. Herbaceous response was also rapid and included a mixture of beakrush and redroot within the first post-burn year, and chain fern (*Woodwardia virginica*), sedges (*Carex* spp.), yellow-eyed grass, redroot, and bur marigold (*Bidens mitis*) within 2-3 years (Cypert 1961). Although some species replacement occurred, most of the herbaceous species established within the first few years were present 15 years later. However, woody species were slowly displacing herbaceous growth. Several of the species and trends recorded in the seed

bank study herein were similar to those recorded in Cypert's post-burn study plots (Cypert 1973, 1961). Disparities suggest that post-burn herbaceous response is not completely dependent on the seed bank. Walter's sedge (*Carex walteriana*) and chain fern were important species in the initial post-burn recovery in the late 1950s; although these species were abundant in this study where seed bank samples were collected, they were poorly represented in the seed bank samples. Walter's sedge may recover from surface fires that do not burn into the peat and kill the roots, by resprouting rather than seed germination, which gives the species a competitive edge over those recovering from fire by germination. Chain fern was not recorded in the seed bank samples during the experiment interval, but appeared in sample trays that were retained for seedling maturation and identification within a year of sample collection. Fern spores are probably abundant in the peat samples, and their presence was overlooked due to the brevity of the germination study. Fern spores were estimated to be 8-100 times more abundant than seeds in Malaysian peat (Wee 1974). Redroot seedlings originated from seeds and rhizome segments (3%) in the Okefenokee Swamp peat samples. Sandhill cranes (*Grus mexicana*) graze heavily on redroot shoots and rhizomes in Okefenokee Swamp (Cypert 1961); regrowth from rhizome segments may provide more rapid recovery from this feeding activity than germination from seeds. Other persistent species recorded in abundance in the post-burn plots (e.g., yellow-eyed grass, 3-square, *Dulichium arendinaceum*, beakrush) (Cypert 1973, 1961) were also abundant in the seed bank samples in this study.

Seed bank differences among areas, structural zones, treatment responses, seasons, and standing vegetation composition help elucidate current and potential spatial diversity in the Okefenokee Swamp vegetation community dynamics. The seed banks sampled in this study display characteristics common to other freshwater wetland systems. Most of the sampled seed pool was comprised of the same few species throughout the swamp. Dominant species observed in this study were similar to those recorded in other seed bank studies (Gerritsen and Greening 1989, Conti and Gunther 1984, Gunther et al. 1984). However, proportions differed as a function of sampling technique and emergence methodology, and also due to pre-sampling conditions in the swamp. Gerritsen and Greening (1989) sampled after a period of low water and their density measurements may have been inflated for drought-response species such as beakrush and redroot, while deep-marsh species may have been under-represented. Their short study duration (during 1 year) also could not quantify annual seed bank variability that would reflect inter-annual environmental variance.

Over-representation of yellow-eyed grass, 3-square, and redroot in the Okefenokee Swamp seed bank may reflect their dispersal mechanism (wind), the large potential seed production contributed annually, and the longevity of their seeds in the submerged sediments. Monocots such as these are not uncommon dominants in wetland seed banks; frequently the dominants in the seed bank are perennials that can produce a large annual seed rain in rapid response to environmental variability, and thus perform as facultative annuals in an otherwise "annual-poor" environment (Leck 1989). This prolific production of seeds results in seed bank persistence that disproportionately

represents the species in the wetland's vegetation history. Although these 3 species were found in the established vegetation of all sampled areas, they were minor standing components of the prairie environment, which comprised <10% of the swamp landscape (see Chapter 4). Assessment of standing vegetation while conducting seed bank studies is integral to recognizing these disproportions (also see van der Valk and Davis 1979).

Forest covered nearly 60% of the Okefenokee Swamp landscape, yet woody species occurring in these areas accounted for <1% of the germinated seeds. Woody seed presence is usually low in wetland seed banks due to low seed production and low seed survival in anaerobic conditions. Unsuitable conditions for germination, type and state of decaying peat, patterns of standing vegetation (which are also affected by seed distribution), and disturbance history also affect woody species' seed survival and seedling establishment (Leck 1989). Many woody wetland species spread vegetatively, or rely on seasonal flooding to distribute their seeds, which may result in concentrations along waterways, drift lines, and high water limits, and create a paucity of seeds in floodplain areas scoured by seasonal flooding. This concentration of woody and herbaceous seeds in areas of the floodplain landscape ultimately contributes to the seed bank and vegetation diversity and standing vegetation distribution and structure. In the Okefenokee Swamp landscape, surface flow is associated with inflowing northwestern streams, the Suwannee and St. Marys River floodplains, and portions of the canoe trails that link the prairies and forested regions to these drainages. Berms of peat and live vegetation border much of this flow network. Although some of these channels are natural topographic lows, many were excavated and have been maintained as boat trails

during the past 100 years. In many places the vegetation along these trails is a product of this maintenance, as peat is elevated, seed banks are exposed, and water and wind dispersed seeds are trapped in the berm vegetation. Local and landscape level processes, such as fire behavior and water movement during low water periods when peat in adjacent areas is exposed, as well as seed and seedling dispersal, are potentially affected by this boat trail system.

Dominant species in the established vegetation may not be well-represented in the seed pool for many reasons. In some wetlands, fluctuations in water levels are necessary to maintain seed bank and floristic diversity (Leck 1989). Complex relationships among the seed bank and established species result where an annual or seasonal drawdown cycle occurs. This requires that inundation-tolerant and exposure-tolerant species coexist and occur simultaneously in the seed bank. Frequently this concentration occurs along the transitional, wetted edge, and not within or outside the wetland (Leck 1989). Many species are tolerant of a range of water levels during recruitment (Keddy and Ellis 1985). Submerged species germinate almost exclusively under flooded conditions, whereas many emergent perennials and mudflat annuals germinate under flooded and drawdown conditions (Leck 1989, van der Valk and Welling 1988). Seedling densities are usually reduced with prolonged flooding; continuous inundation limits seed survival (Leck 1989), and reduces seed bank diversity.

Dispersal mechanisms influence spatial distributions of standing vegetation and their propagules. Nearly equal numbers of wind-dispersed (22 species, of which 6 are woody) and water-dispersed (26 species, of which 7 are woody) species were present in

the Okefenokee Swamp seed banks. However, spatial distributions of these species differed. Of the wind-dispersed species, 50% were found in all sampled areas, whereas only 27% were found in only 1-2 of the sampled areas. Water-dispersed samples were more limited in their distributions; 35% were found in all sampled areas, whereas 39% were found in only 1-2 of the sampled areas. Wind dispersal increases the likelihood that a seed will be distributed away from the parent plant and its seeds, and therefore may lessen intraspecific competition upon germination. Although wind-dispersed species may be abundantly represented in the seed bank, many of the distributed seeds will fall on unsuitable germination sites, and mortality will be high when, if not before, dormancy is broken.

Limitations of hydrochory as the primary seed dispersal mechanism also can influence seed survival and therefore community vegetation dynamics. Titus (1990) found that distribution of floodplain forest seedlings was correlated with microsite type, location, and relationship to floodplain hydrologic environment. Seeds that fall in areas with continuous surface water movement will be transported away from the parent plant and possibly to suitable germination sites as long as buoyancy is maintained. Seasonal inundation results in another seed bank dynamic. Seeds that fall on exposed sediments will remain concentrated in place until seasonal flooding removes them. If dormancy is broken before dispersal, the seedling must gain sufficient stature to survive inundation that will occur with seasonal flooding, and must compete for resources with the parent plant and others in the seed rain. Dehiscense of many riverine and floodplain species corresponds to low water periods, so that when flooding resumes, seed dormancy has

broken and the seed is prepared to germinate following water transport (Leck 1989). Low water periods in Okefenokee Swamp occur in the late spring and autumn. Seed rain of many woody species in the swamp occurs during the late summer and autumn low water period. Although seeds falling in the sill-affected area during low water periods might successfully germinate on exposed peat, seedling survival depends on achieving sufficient height to exceed water levels upon re-flooding. In the impounded area this re-flooding occurs with the winter storm fronts and continues into early spring. If drawdown to expose these seedlings does not again occur by the growing season, the previous year's seedlings will not survive. Greatest seed survival occurs when water-dispersed seeds are intercepted by floating debris, concentrate at the edges of receding water levels, and settle with drawdown before seed buoyancy declines (Titus 1990, Schneider and Sharitz 1988, 1986). Dependence on hydrochory for seed dispersal usually limits the spatial extent because of the temporal patterns of hydrologic cycling. Therefore, greater incorporation of wind-dispersed seeds into the seed bank over a greater spatial and temporal extent is expected, especially if artificially high water levels and extended hydroperiods are reduced with sill modification.

Seed banks may be more diverse where habitat diversity is high (Leck 1989). The greater the diversity of site microtopography, the greater the number of species that may find suitable germination conditions and subsequently contribute to the standing vegetation and seed pool species richness (Titus 1990). Area, treatment, and structural zone of origin significantly affected Okefenokee Swamp seed bank diversity in this study. Species diversity and richness were greater in exposed conditions, and inter-

sample variabilities in diversity and richness were higher in submerged conditions. Total seedling densities also followed this trend. These trends mirror those of Gerritsen and Greening (1989), although densities for individual species differed. Low species diversity is not uncommon in submerged seed banks (Leck 1989).

Seasonal fluctuations in seedling emergence diversity, richness, and total number were primarily among sample variances; means were not significantly different. These seasonal affects probably reflect the predominant dispersal method, wind, as well as the abundance of persistent species in the seed bank. Most of the germinated species initially release seeds in the late summer and autumn, and these would have been included in the autumn samples. Some species with abundant seed rains are spring seed producers, and their seeds are released early in the growing season. By the spring sample collection, the seed densities of species producing seeds the previous autumn may have declined so that seasonal species differences were apparent, but overall numbers remained high because of the additional recent contributions to the pool by spring seed producers. Seasonal variability in seed density and diversity may also reflect patchiness of the standing vegetation distributions.

Area was a significant factor in estimating species density, diversity, and richness, and differences among areas may also be a function of patchy standing vegetation distributions. Overall seed bank species diversity was highest in Chesser Prairie; seasonal differences in diversity were most apparent in the sill area, where diversity was second to Chesser Prairie in the autumn and lowest of the sampled areas in the spring. This seasonal difference may be attributable to the relatively low abundance

of herbs, most of which are autumn seed producers, and the abundance of shrubs and trees, whose seeds are not long-lived in the seed bank after dehiscence.

Hydrological patterns affect the role seed banks play in wetland vegetation dynamics (Leck 1989, van der Valk and Welling 1988, van der Valk and Davis 1979, van der Valk and Davis 1978, van der Valk 1981). Presence or absence of standing water is the primary "environmental sieve" determining species recruitment or extirpation (van der Valk 1981), although the effect of this condition is not uniform for all wetlands (Leck 1989). Tidal freshwater wetlands experience both inundated and exposed conditions, so that the mere presence of water is not necessarily the determining factor in seed survival and germination (Leck 1989). In contrast seed banks and hydrologic cycling are vital to the long-term survival of marshes of the North American Midwest. Dominant prairie wetland species change with water level fluctuations, but all stages of marsh vegetation are present in the seed bank, and are renewed with water level fluctuation and dispersal from adult plants (Leck 1989, van der Valk and Davis 1979, 1978). In Okefenokee Swamp seed bank composition varies with hydrologic regime. This was illustrated by differences in seed bank composition of vegetation structural zones, as well as differences in species groups based on variability of the collection site hydrologic environment. Highest species richness occurred in structurally complex zones that represented several stages of successional community development (e.g., aquatic prairie-shrubs, herbaceous-shrubs, shrubs, shrubs-herbs-trees), and most sampled species showed some affinity for particular zones overall or by season. These trends reflect the sequences of vegetation succession outlined by Cypert (1972), Duever and Riopelle

(1984, 1983), and Hamilton (1984, 1982). When new vegetation colonizes recently exposed peat, inundation-tolerant species are gradually replaced by those requiring more exposure (Cypert 1972, Duever and Riopelle 1984, 1983). The propagule source for most of this establishment is the seed bank. The temporal sequence of herbaceous and woody species in succession in the Okefenokee Swamp is similar to the spatial sequence of species along the hydroperiod and water depth gradient. Peat supporting associations in later stages of primary succession or secondary succession has accumulated a diversity of seeds over a period of changing environmental conditions. The established vegetation becomes more structurally complex with woody species growth and maturation, while the seed bank continues to hold seeds from species of earlier stages, as well as those transported to the site by wind and water, and a few from woody later stages. Germination and maturation of the early succession species following fires, changes in hydrologic conditions, or die off of competing species and individuals ensures their continuance in the seed pool. Species germinate from the seed pool and survive to reproduce depending on their tolerances to the changing conditions and their ability to coexist with other germinating species (van der Valk and Welling 1988, Fenner 1985).

The structural zones represented by species appearing in successional sequences can also be loosely grouped based on duration, depth, and temporal variability of flooding. The 2-factor gradient of inundation depth and variability along which standing vegetation species are arranged (Chapter 6) also applies to seed bank compositions along these gradients (Figure 7-4). Water depth variability is more consistently tied with species occurrence than absolute water depth, although differences also exist with depth

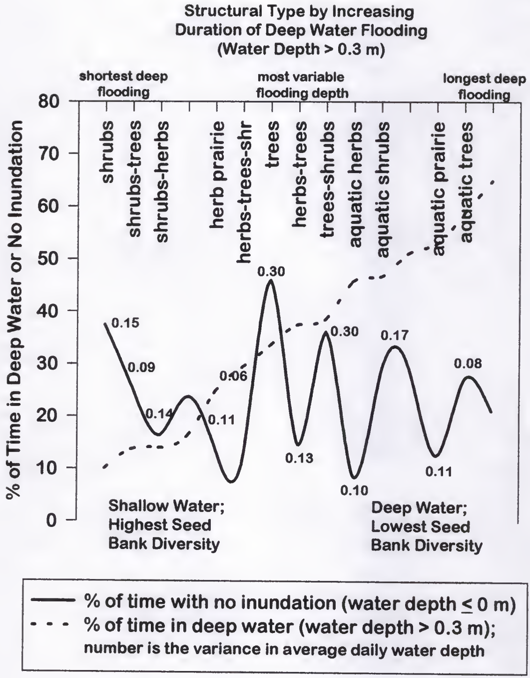


Figure 7-4. Vegetation structural zones arranged with increasing duration of deep water flooding (> 0.30 m; dotted line). Duration of exposed conditions is plotted (solid line), and variance in average daily water depth for each zone type is indicated. Species generally associated with each zone type in the seed bank and established vegetation are listed in Tables 7-4 and 7-6.

of inundation. More species occur as water depth variability declines, particularly in the shallow (0.0-0.3 m) inundation depth range. Similarity between standing vegetation and seed bank composition is highest for those areas with variable, deep water depths. Species occurring in these areas must tolerate both inundated and exposed conditions, which are seasonally predictable in most regions of the swamp where these conditions occur. This relationship between the seed bank and established vegetation floristic diversity is not uncommon in other wetlands with seasonally or annually fluctuating water levels (Leck 1989).

Effects of the Suwannee River Sill on the Okefenokee Swamp Seed Bank

The Suwannee River sill has extended inundation duration and increased flooding depth in a limited area of the swamp (Chapter 3). Throughout the affected area the impact has influenced distributions of some vegetation species, but the affect on species regeneration and distribution in the landscape overall has probably been minor (Chapters 3 and 6), and greater influence on species' distributions can be attributed to fire suppression and early 20th century logging affects (Chapters 4 and 5). Most species in this seed bank study demonstrated distinct differences in germination density under exposed and inundated conditions, which might suggest that these species would occur under constant hydrologic regimes in the swamp. However, most of the species found in the seed bank samples tolerate (as adult plants) a variety of inundation conditions in the swamp (Chapter 6) that are more broad than the experimental conditions affecting the seed bank samples, supporting the idea that many species are broadly tolerant of

inundation conditions during recruitment (Keddy and Ellis 1985). This is probably particularly true of the herbaceous species in the seed bank which are also the initial colonizers in areas undergoing primary and secondary succession. Their ability to colonize is likely in part a function of their plasticity to changing environmental conditions. Woody species may also tolerate a range of germination conditions more broad than provided in this study; however, their slow growth and paucity in the seed bank limits this interpretation.

The relatively constant, deep water environment in the impounded area closest to the sill (southeast of Craven's Hammock to Billy's Lake and the Pocket) is affecting a community of species that is scarce in other regions of the swamp. Although partly resulting from the hydrologic character of the floodplain environment that was present before sill construction, its uniqueness is also a product of sill-extended hydroperiods and water depths. This area was heavily logged during the early 20th century and again north and east of the constructed berm prior to sill construction, so that species compositions and distributions had already been altered before sill-induced inundation. However, some trees have survived and produce seeds that usually die before successful recruitment due to artificially high water levels. Occasional individuals, particularly pond cypress, swamp blackgum, and ogeechee lime, successfully germinate and reach heights that exceed inundation before it occurs, or are dormant by winter flooding and are re-exposed during subsequent drawdown. Therefore, recovery potential exists if the area's hydrologic cycling is permitted to assume a more naturally fluctuating regime.

Other species that were completely removed from the area before sill construction or succumbed to flooded conditions after the sill was built may require supplemental seeding for recovery.

Although more abundant than woody seeds in the sill area seed bank, diversity of herbaceous species in this area is also low. Yellow-eyed grass, red root, spikerush (Robin's spikerush, *Eleocharis robbinsii,* and *E. vivipara/baldwinii*), creeping rush (*Juncus repens*), maidencane (*Panicum hemitomon*), fragrant water lily, 3-square, and spatterdock are the predominant herbaceous species in the area; these species occur in the sill-affected area at greater inundation depths, durations, and with generally higher inundation variability than elsewhere in the swamp. Most of these species are wind dispersed, so that a restriction of surface water flow to seasonal cycles will probably not affect seed distribution. However, more frequent drawdown and exposure expected with sill manipulation will probably eliminate water lily and spatterdock from this area since their rhizomes will not tolerate prolonged exposure. Their distributions after initial decline will probably be limited to areas receiving constantly inflowing water, where their rhizomes will remain saturated and contribution to the seed bank will occur annually. As previously flooded area are exposed, woody and herbaceous species less tolerant of inundation will become established from the buried seed pool and from recently wind-dispersed seeds.

CHAPTER 8
SUMMARY AND CONCLUSIONS

This dissertation examines landscape-level processes and composition changes that have occurred in the Okefenokee Swamp during the past 150 years. The affected areas range spatially from hectares to square kilometers, and the duration of these effects ranges temporally from seasons to centuries. The examined processes are human-induced or the result of regional weather dynamics, and are part of the area's past as well as current driving functions of the system. The responses of vegetation species that create the swamp landscape are in part dependent on occurrence of these processes in the swamp's development; if species' tolerances to changes are exceeded, an altered system results. This change might illustrate expected successional development. It might also result in development or evolution of a new system or species domain if the driving functions are absent from the system's developmental history. The dynamic nature of the Okefenokee Swamp landscape is an expression of cross-scale processes and patterns occurring throughout the swamp's development. The direction, cause, and predictability of responses to these driving functions can be identified only through examining the system from the cross-scale perspective, the approach taken in this dissertation research.

Human Activity in the Okefenokee Swamp

The Okefenokee Swamp is a complex of vegetation associations that sequentially develop in an "abbreviated" hydrarch succession. This "abbreviation" results from fire and drought cycles, which interrupt the apparent sequence every few to hundred years, arresting development toward presumably a terrestrial or non-wetland type. The variable intensity and extent of these fires and duration of drought create a response in the vegetation community distributions and compositions that is varied in type and permanency. These features and the driving functions in the swamp landscape were explored with comparisons of maps generated from landscape-level vegetation data and fire occurrence maps, in Chapters 4 and 5.

Chapter 3 explored the hydrologic environment in the swamp, from local to landscape scales using recorder data, topographic surfaces, and a spatial hydrology model. The swamp has a relatively diverse topography; small changes in elevation create differences in water depths and hydroperiods, or hydropatterns. The basins with relatively stagnant, constant water levels, and streams and rivers, with variable, channelized flow draining the northwestern watershed, provide a diversity of hydrologic environments, as do local variances in topography. Hydrologic diversity and drought-fire cycling contribute to development and maintenance of the Okefenokee Swamp landscape mosaic. In the swamp's pre-modern history a dynamic equilibrium may have existed, where change was continual, but the outcome was predictable, i.e., the components and

driving functions were part of the swamp's developmental history. The successional sequences hypothesized by Hamilton (1984, 1982) illustrate this dynamic equilibrium.

Within the past 200 years, however, human modification of the swamp, its surroundings, and the processes that shape the system began to alter the landscape. Soon after the most recent peat accumulations began 6,500 years ago, Indians resided on the interior islands and in the swamp perimeter; the current perception of "natural" development and maintenance of the swamp includes effects of their use of fire to manipulate their environment. Construction of the Suwannee Canal in the late 19th century accelerated stream flow to the west from the central and eastern swamp, especially during high water periods, when the water surface elevation exceeds the natural topographic berms that otherwise impound water east of Billy's Island. Early 20th century logging of pond cypress (*Taxodium ascendens*), slash pine (*Pinus elliottii*), pond pine (*P. serotina*), longleaf pine (*P. palustris*), swamp blackgum (*Nyssa sylvatica* v. *biflora*), and to a lesser extent loblolly bay (*Gordonia lasianthus*) and sweet bay (*Magnolia virginiana*), throughout the swamp was an unprecedented modification to the vegetation. The swamp hydrologic environment and fire ecology were subsequently modified by this cross-scale effect. By the late 20th century the swamp vegetation structure (i.e., proportions of forest, shrub, prairie) was approaching that of pre-logging; however, the species composition had been altered. Forested areas previously dominated by pond cypress were being replace with bay- and gum-dominated associations. These associations require less fire in their maintenance, and may not promote the spread of fire across the landscape. Peat mining followed logging. Dredging and mining processes

were more localized than the preceding logging; however, they also had the potential to alter the swamp environment. Today, the northeastern swamp where this mining occurred is a unique sub-basin, with minimal water level fluctuations, continual shallow flooding, and a diverse assemblage of species. The natural terracing of this region has probably limited the potential drainage effects of the mining canals. These historic modifications were examined in Chapters 2-5.

Not all of the modifications to the swamp were in its past. Current management activities include boat trail maintenance, which has created channelized features that may facilitate drainage at high water levels and accelerate dewatering by evaporation in low water conditions. This activity also suspends, mixes, and exposes peat, alters vegetation structure and creates berms for shallow-water species colonization, and may affect fire movement across the landscape. Wildfire control and prescribed burning in and around the swamp are also part of current management. Fire itself is not a new function in the landscape, but timing, intensity, and pattern of burning in the perimeter uplands have been altered by this management, which subsequently has an effect on swamp fire ecology. Changes in the swamp landscape resulting from historic logging have also influenced historic fires; logging debris probably burned in fires around logging tramlines in the early 20th century. Today, areas previously logged and revegetated with an altered vegetation composition will potentially affect future hydrologic regimes, fire behavior, and landscape response. These effects were discussed in Chapters 4 and 5. The Suwannee River sill is a recent alteration to the swamp hydrologic environment. The sill was built to reduce the intensity, frequency, and extent

of fires originating in the swamp, spreading into the perimeter uplands, or damaging (as then perceived) the swamp. It was also intended to slow erosion of the Suwannee River channel at the south end of Billy's Lake, and thus prevent drainage of the swamp from a breach in this "natural sill". Effectiveness of the sill in achieving these goals was assessed with the swamp hydrology model, discussed in Chapter 3.

These processes, changes, and manipulations have affected the swamp landscape. This cross-scale study used site- to landscape-level sampling to identify short- to long-term processes and effects, and the interactions of these processes in shaping the swamp environment.

Okefenokee Swamp Hydrology

A study of the swamp hydrology and effects of the Suwannee River sill required a diverse, extensive temporal and spatial database; these were developed and analyzed in Chapters 2 and 3. Examination of the swamp topography revealed landscape features that shape the hydrologic environment. The swamp sand basement is a depression in the regional landscape that collects water from the surrounding watershed. Within the swamp are terraces, ridges, and berms in the subsurface sand and surface peat that create sub-basins. Although the predominant trends in the swamp hydrology are weather-driven, there are localized differences that distinguish these sub-basins and the effects of hydrologic manipulations on these areas. Inflowing creeks and outflowing rivers affect surface water flow in the western swamp, whereas evaporative demands are the

predominant feature of water level fluctuations in the eastern swamp. Sub-peat ridges modify water movement and drainage, creating impoundments in the streams and rivers, and locally slowing drainage into and within the Suwannee River; the "natural sill" at the southwestern end of Billy's Lake is one of these features, as are several similar berms in the Suwannee River bed southwest of the refuge boundary. Although the Suwannee River sill also serves as a berm, its effects are limited, due in part to its location and size, but also because the swamp water levels are controlled on a larger scale by regional and seasonal precipitation patterns. This control hierarchy illustrates that the potential effectiveness of any impoundment structure on the swamp's hydrologic system can not be absolute, and therefore performance of the sill as a fire control structure is also limited. The increased water depths and extended flooding created by the sill have had localized effects on the vegetation, however. Woody species' regeneration has been limited in the impoundment area, particularly near the sill structure and in the impounded river floodplain. Herbaceous species diversity has also been reduced in this area. These limitations are results of altered water depth and inundation duration. Seed sources (in the established vegetation and the seed bank) exist to repopulate this area to pre-sill species composition, given more suitable hydrologic conditions, although some species (e.g., slash pine, pond pine, and longleaf pine) are not represented in this seed pool. Breaching the sill dike or opening the sill gates would permit the area to assume the pre-sill fluctuating hydroperiod of a river floodplain in this deepwater swamp, initiating this recovery process.

Okefenokee Swamp Vegetation

The Okefenokee Swamp landscape is a dynamic mosaic of species whose distributions are determined in part by species tolerances to hydropattern and fire. A gradient of hydrologic environments exists in the swamp, that spans a range of flooding depths and durations. Associations of species occur along this gradient, limited to a degree by their tolerances to the gradient of hydropatterns. The gradient of water level variability is fixed by the seasonal precipitation patterns, and location within the swamp. The western swamp, with a steeper topographic gradient and more inflow from the adjacent watershed, is hydrologically more variable than the eastern swamp. Plant composition and distribution differ between these regions, in part due to this hydrologic difference. Water depth also varies in the swamp; however, except in the deepest area created by the sill impoundment, there are few regional differences in swamp vegetation distributions that can be attributed solely to water depth; flooding duration as well as logging and fire history, are also determinants of species occurrence. Subtle differences in species' tolerances to hydrologic environments were discussed in Chapters 6 and 7.

As autogenic succession occurs, site environments and species assemblages change. In the swamp this progression of vegetation composition is disrupted by fire, which varies in intensity, extent, and frequency due to seasonal precipitation and regional climatic trends. In the absence of fire, the progression continues toward development of a mixed swamp, dominated by loblolly bay (*Gordonia lasianthus*), sweet bay (*Magnolia*

virginiana), and swamp blackgum (*Nyssa sylvatica* v. *biflora*) (Hamilton 1984, 1982). Areas of the swamp that undergo frequent and severe burning are arrested in this succession, and cycle among prairie, shrub, and mixed shrub-forest forms; those that do not severely burn are eventually composed primarily of mixed swamp, which is currently a relatively rare type in the swamp landscape. The peat record in the swamp indicates that the swamp has a history of fire, which consumes peat and subsequently raises water depths. The abundance of prairie and shrub vegetation in the eastern swamp is in part due to a history of fire, which is less prevalent in the western swamp. The historic swamp was heavily populated with cypress in the northwestern basin. Although fire frequency and severity in this area were probably limited, occasional severe fires pruned vegetation competing with the cypress overstory. Fluctuating water levels permitted rapid decomposition of peat and peat transport from the floodplain, which also may have controlled the spread of competing species. Logging in the early 20th century, the sill impoundment effects in the western swamp, and recent wildfire suppression activities have disrupted these fire and hydrology cycles throughout the swamp, and the composition and distributions of swamp vegetation communities are illustrating the effects today, as recognized in Chapters 4 and 5.

The swamp's sand basement is blanketed with a layer of peat, in places > 3 m thick. This peat is comprised of previously standing vegetation from the site, or may have been transported to the site by wind or water flow. Although most of the peat is decaying plant material, seeds are also abundant in the peat; this propagule pool may represent the standing vegetation as well as the site's historic composition. As suitable

germination conditions occur, these seeds may initiate secondary succession of the site. Transport of seeds of woody species to the developing site continues this succession, which may be arrested or delayed by fire or changes in the hydrologic environment. This seed bank cycling is an integral component of the dynamic swamp landscape, that will continually promote its development, given appropriate conditions. This component of swamp ecology was examined in Chapter 7.

The Okefenokee Swamp Landscape

The sill was constructed to impound water, and it is doing so in approximately 18% of the Okefenokee National Wildlife Refuge, primarily in periods of abundant precipitation. However, wildfires are most frequent and most extensive during low precipitation periods; the sill impounds little water during extensive periods of minimal precipitation. Therefore its affect as a fire control structure is limited. Model simulations discussed in Chapter 3 indicate its spatial effects extend from the sill berm to Craven's Hammock in the northwestern swamp, to south Sapling Prairie and the western perimeter of Chase Prairie, and the northeastern end of Billy's Island. This area encounters extended hydroperiods, increased water depths, and reversals in water flow direction under extreme high water level conditions in the Suwannee Canal to Chesser Prairie area. Changes in vegetation distributions since sill construction have not been limited to the impounded area, however, nor do they indicate flooding effects

exclusively. Vegetation distributions and compositions continue to respond to the early 20th century logging effects, as well as the more recent fire history.

Yin and Brook (1992b) and Yin (1990) hypothesized that there is a 100+ year cycle of severe wildfire in the swamp, preceded by a period of reduced precipitation that results in severe drought. This burn interval is also suggested in the peat, where charcoal deposits indicate succession-arresting fires occurring throughout the swamp history. Although intervening periods of reduced precipitation and wildfire occur, it is probably severe fires that occur during periods of extreme drought that have a long-term affect on the swamp landscape composition. It is this gradient of fire intensity, extent, and frequency, coupled with limitations of the hydrologic environment on species distributions and compositions, that give the swamp the appearance of a "moving mosaic".

This dynamic continues in the swamp today. However, the types, intensities, and extent of the processes driving historic change in the landscape have been altered by humans during the past 150 years; these changes continue to affect the swamp today across spatial and temporal scales. In response to these altered driving functions, as well as those shaping the system throughout its development, the swamp landscape continues to evolve toward a stability domain that may not have previously occurred.

APPENDIX A
SUWANNEE RIVER SILL AUTHORIZATION BY CONGRESS

PUBLIC LAW AUTHORIZING CONSTRUCTION OF THE SUWANNEE RIVER SILL (Laws of the 84th Congress-2nd Session, Chapter 742, Public Law 81-810, 70 Statute 668, pages 781-782)

An act to provide for the protection of the Okefenokee National Wildlife Refuge, Georgia, against damage from fire and drought.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, that (a) for the purpose of protecting the natural features and the very substantial public values represented in the Okefenokee National Wildlife Refuge, Georgia, from disastrous fires such as those which swept over 80 per centum of the area between October 1954 and June 1955, and for the purpose of safeguarding the forest resources on more than four hundred thousand areas of adjoining lands recently damaged by wildfires originating in or sustained by the desiccated peat deposits in the Okefenokee Swamp, the Secretary of the Interior shall construct a continuous perimeter road around the Okefenokee National Wildlife Refuge with additional fire access roads (leading from such perimeter road) in and around such refuge; and for the purpose of protecting such refuge against damage from drought he shall construct a sill and dike in the Suwannee River near the point where the river leaves the refuge together with additional sills in the Old Saint Marys River Canal and at such other points within the refuge as he may determine to be necessary to prevent drainage of the Okefenokee Swamp during periods of drought such as those which occurred in 1953-1955 and other years.

(b) The Secretary of the Interior is authorized and directed to conduct such surveys as he deems necessary to provide more adequate protection for the Okefenokee National Wildlife Refuge, through the development and construction of perimeter and fire

access roads and the installation of water controls as described in subsection (a), against the damaging effects of fire and drought.

(c) The Secretary of the Interior is authorized and directed to cooperate with State and local authorities in protecting public and private lands from wildfires originating in or sustained by the Okefenokee National Wildlife Refuge by integrating the perimeter road and fire access roads with existing woods roads in such manner as he determines will best carry out the purpose of this Act.

Sec. 2. There are hereby authorized to be appropriated to carry out this Act (1) the sum of $453,500 for the construction of a continuous perimeter road around the Okefenokee National Wildlife refuge and approximately one hundred and sixty-two miles of fire access roads, together with necessary bridges and culverts, in and around such refuge, and (2) the sum of $275,000 for the construction of a sill and dike in the Suwannee River and sills at other appropriate points in the Okefenokee National Wildlife Refuge.

Approved July 26, 1956.

APPENDIX B
COMPUTER MODEL CODE FOR HYDRO-MODEL

HYDRO-MODEL is written in ARC Macro Language (AML) and will run on ACRINFO-GRID version 7.0 or later. The model is a collection of modules initiated by the user from the model menu. The model AMLs are listed below in sequence of their introduction in the model processing. The model flowchart, sequence of AMLs, and menu interface are shown in Figure 3-2 and Figure 3-4, respectively.

Hydro-model.aml

```
/* hydro-model.aml
/**************************************************************************
/*
/*        Hydro-model.aml is the Master Hydrologic Model AML.
/*        This aml sets global variables and threads hydro-model.menu
/*        This aml controls the location of data directories, amls,
/*        menus, etc.
/*
/*        Called by: User at Arc prompt
/*        Calls: Threads hydro-model.menu
/*
/*        Written by Nicholas J. Ansay & Cynthia S .Loftin
/*        Revised 12/03/96
/*
/*
/**************************************************************************

&echo &off
&severity &warning &routine warning
```

```
&severity &error   &routine error

&amlpath /disks/hovel/hydro-model/amls    /* Path to hydro-model Aml's
&menupath /disks/hovel/hydro-model/menus  /* Path to hydro-model Menu's

/* Path to hydro-model's home directory
&sv .hydro-model-home /disks/hovel/hydro-model

/* Path to PET and Precipitation Surface Grids.
&sv .pet-prec-surfaces /disks/hovel/hydro-model/pet-prec

/* Path to (back-sillz, front-sillz, inflow-zones, outflow-zones,
/* refuge-mask, roughness100m, roughness500m, scra-zone, & start-depth)
&sv .grids /disks/hovel/hydro-model/grids

/* Path to coverages used
   /* in the model :
   /* FIR-ISLD, IN-3093, INFLOW-ZONES, OUT-3039
   /* OUTFLOW-ZONES, PET-3093,   PREC-3093
   /* REFBND, REFBND-REV, SCRA-ZONE, SILL
   /* STATIONS
&sv .coverages /disks/hovel/hydro-model/coverages

/* Path to topo surfaces
&sv .topodata /disks/hovel/hydro-model/topo-surfaces

/************************* Set Path to Results ****************************
/* A temporary directory used to store bi-monthly
/* interim results (e.g.,End water, Depth of water)
&sv .temp   /disks/habitat/cyndy/results80s
/*************************************************************************

/* Location of Results (e.g.,End water and depth of water)
&sv .results  %.temp%  /* Note the temp directory has evolved into
                /* the results directory

/* Location of remap tables,
/* Arcplot Key files, and shadesets
&sv .map-tools /disks/hovel/hydro-model/map-tools

&sv .programstatus

/* Location of error messages
```

```
&sv .messages /disks/hovel/hydro-model/messages

/* Set primary data to variable names
&sv .prec   %.coverages%/prec-3093   /* Location of precip point coverages
&sv .pet    %.coverages%/pet-3093    /* Location of PET point coverages
&sv .refbnd  %.coverages%/refbnd     /* Refuge Boundary

/* If  .inflow and .outflow are changed, %.grids%/flow.rel must be
/* modified to reflect the new name.pat of the inflow and or outflow point file
/****outflow files can be nosillout6093 or out-3093****************
&sv .inflow  %.coverages%/in-3093   /* Location of Stream Inflow Point cover
&sv .outflow %.coverages%/out-3093  /* Location of Stream Outflow Point cover

/* Check  stations is a point file of recorder locations used to check
/* and verify model results
&sv .checkstations /disks/hovel/hydro-model/end-water-checks/stations

/* Set Processing Mask and Model Cell Resolution
&sv .mask    %.grids%/refuge-maskr
&sv .cellsize 500

/*Run amls or menus
/* display 9999 3
&term 9999

/*check program environment
&if [locase[show program]] ne arc &then quit

&thread &focus &on &all
&thread &create HYDRO &menu hydro-model.menu &pulldown &position &uc ~
&stripe 'Okefenokee Hydro Model'

&thread &delete &self

&return

/*Bail-out Routines

&routine warning
&severity &warning &ignore
&type A warning condition occurred.
&return
```

```
&routine error
&severity &error &fail
&type An Error has occurred in "Hydro-model.aml". ...
&return &error Terminating program "Hydro-model.aml".
```

Hydro-model.menu

```
/* Hydro-model.menu
/**********************************************************************
/*
/*
/*
/*        Master Menu for Hydro Model.
/*        Hydro-model.menu is the primary interface to
/*        the HYDRO-MODEL.  It allows the user run
/*        the following menus or aml's:
/*
/*        Model:
/*           Run Hydro Model - run-hydro.menu:
/*        Analyze Results:
/*           Check Stations    - check-stations.menu
/*           Display Results   - display.aml
/*        Quit:
/*        Arc Prompt: &tty
/*
/*        Revised 11/5/96
/*        Written by Nicholas J. Ansay and Cynthia S. Loftin
/*
/*
/**********************************************************************

Model
  'Run Hydro Model' &thread &create HYDRO2 &menu run-hydro.menu &position
&below &thread HYDRO &stripe 'Hydro Model'
'Analyze Results'
  'Check Stations' &thread &create CHECK-STATIONS &menu check-stations.menu
&position &below &thread HYDRO &stripe 'Check Stations'; &thread &focus &on
CHECK-STATIONS
  'Display Results ' &thread &create DISPLAY &run display.aml
Quit &thread &delete &all
```

```
Tools
  'Arc Prompt' &tty

  'Trash Results' &r trash-results.aml
```

Run-hydro.menu

```
/* run-hydro.menu
/**************************************************************************
/*
/*
/*
/*          Form Menu to input data & dates to hydro model
/*          Written by Nicholas J. Ansay and Cynthia S. Loftin
/*          Run-hydro.menu is called by Hydro-model.menu and it runs
/*          run-hydro-model.aml.
/*              Revised 2/27/97
/*
/*               VARIABLES SET
/*
/* startyear            Sets the Starting Year
/* emonth               Ending Month
/* eyear                Ending Year
/* percent-of-pet1      Percent Pet value for April-May, Oct-Nov Little
/*                      Rain, High Evap
/* percent-of-pet2      Percent Pet value for June-Sept, High Evap, High
/*                      Rain
/* percent-of-pet3      Percent Pet value for Dec-March, Average Rain,
/*                      Little Evap
/* percent-of-inflow    Percent of inflow water to move
/* percent-of-standing  Percent of water to move in all other cells that
/*                      are not in flow zones (e.g.,inflow-zones or
/*                      scra-inflow)
/* use-roughness        Check Box to control the use of hydrology equations
/*                      which use roughness derived from vegetation, and
/*                      slope derived from the topo surface.
/* pixels-to-move-water  Checking "Use Roughness Grid" will make the model
/*                      use roughness coefficients to move water instead
/*                      of the value set by the "All Other Cells" slider.
/* suwannee-outflow-adj  Adjustment of outflow for the Suwannee River outflow
```

```
/*                    zone.
/*
/* ************************************************************************

          Start Year

  %startyear

        Month    ^Year
  Ending:   %emonth %eyear

 -------------------------------------
       Percent PET to Use

 April-May, Oct-Nov Little Rain, High Evap:
 %pet1
 June-Sept, High Evap, High Rain:
 %pet2
 Dec-March, Average Rain, Little Evap:
 %pet3

 -------------------------------------
      Percent Water to Move

 Inflow Zones:
 %inflow
 -------------------------------------

       Suwannee Outflow Adjustment
            %suwannee-outflow-adj

        # of Pixels to Move Water
        Pixel Size is 500 Meters
            %pixels-to-move-water

         %apply   %cancel

%startyear CHOICE syear SINGLE 1941 1950 1960 1970 1980 1990
%emonth INPUT EMONTH 7 TYPEIN YES SCROLL NO ~
 REQUIRED ~
 HELP 'Ending Month' ~
 NEXT %eyear ~
 INITIAL '12' ~
```

```
 RANGE 1 12 ~
 INTEGER
%eyear INPUT EYEAR 7 TYPEIN YES SCROLL NO ~
 REQUIRED ~
 HELP 'Ending Year' ~
 INITIAL '1993' ~
 RANGE 1930 1993 ~
 INTEGER
%pet1 SLIDER percent-of-pet1 30 TYPEIN NO ~
 INITIAL 1 ~
 STEP .05 ~
 REAL 0.000 1.500
%pet2 SLIDER percent-of-pet2 30 TYPEIN NO ~
 INITIAL 1 ~
 STEP .05 ~
 REAL 0.000 1.500
%pet3 SLIDER percent-of-pet3 30 TYPEIN NO ~
 INITIAL 1 ~
 STEP .05 ~
 REAL 0.000 1.500

%inflow SLIDER percent-of-inflow 40 TYPEIN NO ~
 INITIAL .01 ~
 STEP .001 ~
 REAL 0.000 .02

%suwannee-outflow-adj INPUT .suwannee-outflow-adj 4 INITIAL 0.0 Range 0 1 ~
  TYPEIN YES REAL

%pixels-to-move-water INPUT pixels-to-move-water 3 INITIAL 10 Range 1 50 ~
  TYPEIN YES INTEGER

%apply BUTTON 'APPLY' ~
 &thread &create RUNHYDRO &r run-hydro-model.aml %syear% %emonth%
%eyear% %percent-of-pet1% ~
   %percent-of-pet2% %percent-of-pet3% %percent-of-inflow%
%.suwannee-outflow-adj% %pixels-to-move-water%

%cancel BUTTON CANCEL 'CANCEL' &return
%FORMOPT SETVARIABLES IMMEDIATE MESSAGEVARIABLE msg
```

<u>Run-hydro-model.aml</u>

```
/* run-hydro-model.aml
/***********************************************************************
/*
/*          Run-hydro-model.aml is the main aml that
/*          runs Phase1.aml, Phase2.aml, and Phase3.aml
/*          of the Hydro-model
/*
/*          Called From: Run-hydro.menu
/*          Calls: Phase1.aml, Phase2.aml, Phase3.aml
/*
/*          Written By Nicholas Ansay & Cynthia S. Loftin
/*
/*                    VARIABLES LIST
/*
/* .topodata              Location of Toposurfaces
/* .grids               Location of Grids
/* .startwd               Prefix for start water grid
/* toposurface              TOPO surface used in model
/* startyear              Holds the Start Water Year
/* bmonth                 Beginning Month
/* byear                Beginning Year
/* emonth                 Ending Month
/* eyear                Ending Year
/* percent-of-pet1          Percent Pet value for April-May, Oct-Nov Little
/*                   Rain, High Evap
/* percent-of-pet2          Percent Pet value for June-Sept, High Evap, High
/*                   Rain
/* percent-of-pet3          Percent Pet value for Dec-March, Average Rain,
/*                   Little Evap
/* percent-of-inflow        Percent of inflow water to move in inflow zones
/* use-roughness            True or False flag which tells the model to
/*                   use roughness coefficients instead of percent-of-
/*                   standing to determine how much water is to be moved.
/* pixels-to-move-water     Value used by flowaccum.aml run in Phase3.aml of
/*                   the hydro-model.  This value sets the distance
/*                   a cell of water should move.
/* I, j,k              Counter Variables for year, month, interval
/*.precip-100th-quartile    Keeps a running total of how many times precip
/*                   was between the 75th and 100th quartile.  This
/*                   has been defined in Phase3.aml.
/* sdate, stime, edate, etime Tracks start and end time of model
/*
/*
```

```
/*                    GRIDS & COVERAGES
/* toposurface           Toposurface used in model
/* startwd-%startyear%      Start water grid for starting year
/* no-silladjf         Toposurface without sill adjusted for kriging errors
/*                   and filtered with a 5x5 mean kernel
/* close-sladjf         Toposurface with sill adjusted for kriging errors
/*                   and filtered with a 5x5 mean kernel

/*                      FILES
/* summary.dat          Hydro-model summary report written to the directory where
/*                   the model was run from.  This report is then used by
/*                   check-stations.aml to add a header to the resulting
/*                   data file produced by check-stations.aml

/*************************************************************************

/*********************** MODIFICATION LOG******************************
/* 03/10/97 - Adding adjustment for stream flow for high rainfall events.
/* 03/25/97 - Removed Outflow and redesigned the northwest sheet flow zone
/* 04/22/97 - Added an outflow zone (called suwan-outflow back to the model)
/*************************************************************************
&args startyear emonth eyear percent-of-pet1 ~
    percent-of-pet2 percent-of-pet3 percent-of-inflow ~
    suwannee-outflow-adj pixels-to-move-water

&severity &warning &routine warning
&severity &error   &routine error

&thread &delete HYDRO
&thread &delete HYDRO2

&sv sdate = [date -cal]
&sv stime = [date -ampm]

/* Set byear based on start year variable and bmonth = 1
&sv byear = %startyear%
&sv bmonth = 1

/* Starting water depth used to prime model
&sv .startwl %.grids%/startwd-%startyear%

/* Check to see if these files exist for the range of dates, if so bail
&call files-exist
```

```
&type
&type Hydro Model Start Time is: %sdate% %stime%
&do I = %byear% &to %eyear% &by 1

/************************Set toposurface **********************************
/*********************no sill= no-silladjf**********************************
/******************closed sill= closed-sladjf*******************************
  /* Set which topo-surface to use
  &if %I% < 1960 &then &sv toposurface = %.topodata%/no-silladjf
  &else &sv toposurface = %.topodata%/closed-sladjf
/*************************************************************************

  &do j = %bmonth% &to 12 &by 1

    /*do loop for interval
    &do k = 1 &to 2 &by 1
    &type
    &type
    &type Processing Year: %I% Month: %j% Interval: %k% ...

    /* Create In H20 grid for first phase of Hydro model
    &type
    &sv time = [date -ampm]
    &type PHASE I:  Create Starting Water Volume (%time%)
    &r phase1.aml %I% %j% %k%
    &type

    &sv time = [date -ampm]
    &type PHASE II:  Create Netflow Water Volume (%time%)
    &r phase2.aml %I% %j% %k% %percent-of-pet1% %percent-of-pet2% ~
            %suwannee-outflow-adj% %toposurface%

    &type
    &sv time = [date -ampm]
    &type PHASE III: Create End Water Elevation Grid (%time%)
    &r phase3.aml %I% %j% %k% %toposurface% %percent-of-inflow% ~
            %pixels-to-move-water%

    &end /* End interval loop

  &if %j% = %emonth% and %I% = %eyear% &then &goto FINISHED
  &end  /* End month loop
```

```
  &sv bmonth = 1

&end /* End Year Loop

&if [show program ] = GRID &then quit
&label FINISHED

&call finish-up

&return

/*Bail-out Routines

&routine warning
&severity &warning &fail
&type A warning condition occurred.
&call finish-up
&return &error


&routine error
&severity &error &fail
&type An Error has occurred in "Run-hydro-model.aml" of the Hydro Model. ...
&call finish-up
&return &error

&routine finish-up
&messages &on

/* Compute Ending Time of Model
&sv edate = [date -cal]
&sv etime = [date -ampm]

&if [exists summary.dat] &then &sv = [delete summary.dat  -file]

&sv summary-file-unit = [open summary.dat summary-file-stat -write]

&if  %summary-file-stat% = 0 &then &do /*Line 172

&sv summary-write-stat = [write %summary-file-unit% [quote '****************
Hydro Model Summary *****************']]
&sv summary-write-stat = [write %summary-file-unit% ' ']
&sv summary-write-stat = [write %summary-file-unit% [quote Hydro Model Start Time
```

```
is: %sdate% %stime%]]
&sv summary-write-stat = [write %summary-file-unit% [quote Hydro Model End Time
is: %edate% %etime%]]
&sv summary-write-stat = [write %summary-file-unit% ' ']
&sv summary-write-stat = [write %summary-file-unit% [quote Model Start & End Dates:
%bmonth%/%byear% to %j%/%I%]]
&sv summary-write-stat = [write %summary-file-unit% ' ']
&sv summary-write-stat = [write %summary-file-unit% [quote Toposurface Used:
%toposurface% ]]
&sv summary-write-stat = [write %summary-file-unit% ' ']
&sv summary-write-stat = [write %summary-file-unit% [quote # Of Pixels to Move
Water: %pixels-to-move-water%]]
&sv summary-write-stat = [write %summary-file-unit% ' ']

&sv summary-write-stat = [write %summary-file-unit% 'The following options were used
to run the model']
&sv summary-write-stat = [write %summary-file-unit% ' ']
&sv summary-write-stat = [write %summary-file-unit% '          Percent PET Values']
&sv summary-write-stat = [write %summary-file-unit% [quote April-May, Oct-Nov
Little Rain, High Evap: %percent-of-pet1%]]
&sv summary-write-stat = [write %summary-file-unit% [quote June-Sept, High Evap,
High Rain:        %percent-of-pet2% ]]
&sv summary-write-stat = [write %summary-file-unit% [quote Dec-March, Average
Rain, Little Evap:    %percent-of-pet3% ]]
&sv summary-write-stat = [write %summary-file-unit% ' ']
&sv summary-write-stat = [write %summary-file-unit% '        Percent of Water to move']
&sv summary-write-stat = [write %summary-file-unit% [quote Inflow, to Move:
%percent-of-inflow%]]

&end /*end print to summary.dat file
&sv closestat = [close -all]

&type '**************** Hydro Model Summary ****************'
&type
&type Hydro Model Start Time is: %sdate% %stime%
&type Hydro Model End Time is: %edate% %etime%
&type
&type Model Start & End Dates: %bmonth%/%byear% to %j%/%I%
&type
&type Toposurface Used: %toposurface%
&type
&type # Of Pixels to Move Water: %pixels-to-move-water%
&type
```

```
&type The following options were used to run the model
&type
&type '         Percent PET Values'
&type April-May, Oct-Nov Little Rain, High Evap: %percent-of-pet1%
&type June-Sept, High Evap, High Rain:        %percent-of-pet2%
&type Dec-March, Average Rain, Little Evap:     %percent-of-pet3%
&type
&type '        Percent of Water to move'
&type Inflow, to Move: %percent-of-inflow%

&if [show program] = grid &then quit
&thread &create HYDRO-AML &r hydro-model.aml
&return

&routine files-exist
&do  I = %byear% &to %eyear% &by 1
&sv bmonth2 = %bmonth%
  &do j = %bmonth2% &to 12 &by 1

    &if [exists %.results%/ewat%I%%j% -grid] = .TRUE. &then &do
    &popup %.messages%/file-exists.txt 8 50 3 2
    &goto FINISHED
    &end /* End Do

    &if [exist %.results%/dwat%I%%j% -grid] = .TRUE. &then &do
    &popup %.messages%/file-exists.txt 8 50 3 2
    &goto FINISHED
    &end /*End Do

  &if %j% = %emonth% and %I% = %eyear% &then &goto BREAK-MONTH
  &end  /* End month loop

 &sv bmonth2 = 1

&end /* End Year Loop
&label BREAK-MONTH
&return /* End file-exist routine
```

<u>Phase1.aml</u>

```
/* phase1.aml
```

```
/*********************************************************************
/*
/*      Phase1.aml computes the first phase of the hydro-model to
/*      create a surface called inh20xxx where xxx specifies the year,
/*      month, & interval when water that came into the Swamp.
/*
/*      Called From: run-hydro-model.aml
/*      Calls:
/*      Written by Nicholas Ansay & Cynthia S. Loftin
/*      Revised 04/18/97
/*
/*                VARIABLE LIST
/*
/* i,j,k            Counter Variables for year, month, interval
/* .prec            Point coverage with Precipitation data
/* .refbnd          Coverage defining the refuge boundary
/* dsc$ymin, dsc$xmin    Arc/Info defined Variables
/* dsc$ymax, dsc$xmax    Arc/Info defined Variables
/* ymin, xmin,ymax,xmax  Min/Max of refuge boundary
/* .cellsize        Sets the cell size for the grid env
/* .mask            Processing masked that defines the refbnd
/* .pet-prec-surfaces    Location of precip and PET surfaces
/* .prec            Identifies Precip Point Coverage
/* prck%I%%j%%k%         Precipitation surface for period i,j,k
/* .grids           Location of grids used in the model
/* .inflow          Identifies the inflow point coverage
/* .startwl         start water elevation of the model
/*
/*
/*                GRIDS & COVERAGES
/*
/* inflow-zones       Defines Inflow zones
/* inh20%I%%j%%k%        This is the result of Phase1 (i.e.,this
/*                 is the in water grid)
/* tmp%I%%j%%k%          Holds temporary result (i.e.,lattice form
/*                 of the precip tin)
/* tin%I%%j%%k%          Tin of precipitation for a specific i,j,k
/*
/*                 RELATES
/*
/* flow.rel           This relate is stored in the grids directory
/*                 and links inflows and outflow point coverage
/*                 pats to inflow and outflow grid zones
```

```
/*
/************************************************************************

/**********************MODIFICATION LOG*******************************

/* 04/18/97  - Commented Code

/************************************************************************

&args I j k


&severity &warning &routine warning
&severity &error   &routine error

&messages &off &info

/*&messages &on
/* Perform Arc Commands First

/*************  Create Inflow and Precipitation Grids *********************

    /*Create Precipitation Surface
/*    &type '        Creating Precipitation Surface ...'

    /*Tin Point File
/*    &type '        Computing Tin & Lattice of Precipitation Data ....'
/*    createtin %.temp%/tin%I%%j%%k%
/*    cover %.prec% point two-wk-prec-m # # year = %I% and month = %j% ~
/*                and interval = %k%
/*    end

    /*Find Mapextent of Refuge BND
/*    &describe %.refbnd%
/*    &sv xmin = %dsc$xmin%; &sv ymin =  %dsc$ymin%
/*    &sv xmax = %dsc$xmax%; &sv ymax = %dsc$ymax%

    /*Tin Lattice
/*    tinlattice %.temp%/tin%I%%j%%k% %.temp%/tmp%I%%j%%k% quintic
/*    %xmin%, %ymin%
/*    %xmax%, %ymax%
/*    ~
/*    %.cellsize%
```

```
/*     kill %.temp%/tin%I%%j%%k% all

/************ Create INH20 in Grid Env *****************************

/*check Program Env and Change to grid env
display 0
&if [show program] = ARC &then &do
grid
&end


/*Set Grid Analysis Env
setwindow %.refbnd%
setmask %.mask%
setcell %.cellsize%
setcell maxof

 /* Check for negative values in the precip lattice that may occur due to
 /* the Interpolation method used

/* %.pet-prec-surfaces%/prck%I%%j%%k% = ~
/*      con(%.temp%/tmp%I%%j%%k% < 0, 0, %.temp%/tmp%I%%j%%k%)

    &type '        Creating INH2O Grid ...'

    /* Create inflow with relates.  The relate, flow.rel is stored in
    /* the grids directory set in hydro-model.aml.  This relate provides
    /* access to inflow values stored in %.inflow%.pat. This variable is set
    /* in hydro-model.aml.
    relate restore %.grids%/flow.rel

    /* clear any previous selection
    clearselect %.inflow%.pat info
    reselect %.inflow%.pat info year = %I% and month = %j% and ~
                   interval = %k% or zone = 0

    /* Compute the inh20 grid for the specified year, month, and interval
    %.temp%/inh20%I%%j%%k% = %.startwl% + ~
                   %.grids%/inflow-zones.inflow//depth-zone + ~
                   %.pet-prec-surfaces%/prck%I%%j%%k%

    /*Kill Intermediate Steps
    &type '        Removing Intermediate Results ...'
```

```
    /*kill %.temp%/prck%I%%j%%k%  all
    /*kill %.temp%/tmp%I%%j%%k% all

/* quit /* Quit grid env

&return

/*Bail-out Routines

&routine warning
&severity &warning &ignore
&type A warning condition occurred in "Phase1.aml" of the Hydro Model. ...
&return &error Terminating program "Phase1.aml".

&routine error
&severity &error &fail
&type An Error has occurred in "Phase1.aml" of the Hydro Model. ...
&return &error Terminating program "Phase1.aml".
```

Phase2.aml

```
* Phase2.aml
/**********************************************************************
/*
/*      Phase2.aml computes the second phase of the hydro-model to
/*      create a surface called netxxx where xxx specifies the year,
/*      month, and interval when water entered and left the swamp.
/*
/*      Called From: run-hydro-model.aml
/*      Calls:
/*      Written by Nicholas Ansay & Cynthia S. Loftin
/*      Revised 04/18/97
/*
/*                  VARIABLE LIST
/*
/* i,j,k            Counter Variables for year, month, interval
/* .pet             Point coverage with PET data
/* .refbnd          Coverage defining the refuge boundary
/* dsc$ymin, dsc$xmin    Arc/Info defined Variables
/* dsc$ymax, dsc$xmax    Arc/Info defined Variables
/* ymin, xmin,ymax,xmax  Min/Max of refuge boundary
```

```
/* .cellsize          Sets the cell size for the grid env
/* .mask              Processing masked that defines the refbnd
/* .pet-prec-surfaces  Location of precip and PET surfaces
/* .temp              Working directory and final results
/* .grids             Location of grids used in the model
/* .outflow           Identifies the outflow point coverage
/* .startwl           Start water elevation of the model
/* percent-of-pet1,2,3  PET is controlled differentially by period, we want
/*                to modify our calculated PET values.  The three
/*                periods are: April-May, Oct-Nov
/*                little rain, high evap therefore, use percent-of-pet1;
/*                June - Sept, high evap and high rain therefore use
/*                percent-of-pet2; Dec-March, average rain, little evap
/*                therefore, use percent-of-pet3
/* PET-multiplier     Holds the results of which percent-of-pet to use
/*
/*
/*                    GRIDS & COVERAGES
/*
/* veg-pet-coef       Grid that holds PET coefficients for different
/*                vegetation classes
/* net%I%%j%%k%       This is the results of Phase 2.  It holds the net
/*                water balance
/* tin%I%%j%%k%       Tin of PET for a specific i,j,k
/* toposurface        Current topo surface
/* inh20%I%%j%%k%     This is the result of Phase1 (i.e.,this
/*                is the in-water grid)
/* tmp%I%%j%%k%       Holds temporary result (i.e.,lattice form
/*                of the precip tin)
/* inh20%I%%j%%k%     This is the result of Phase1 (i.e.,this
/*                is the in-water grid)
/* pet%I%%j%%k%       PET surface for period i,j,k
/* veg-pet-coef       Grid that holds PET coefficients for different
/*                vegetation classes
/*
/*                    RELATES
/*
/* flow.rel           This relate is stored in the grids directory
/*                and links inflows and outflow point coverage
/*                pats to inflow and outflow grid zones
/*
/*************************************************************************
&args I j k percent-of-pet1 percent-of-pet2 percent-of-pet3 toposurface
```

```
/**********************   MODIFICATION LOG ***************************/

/* 02/03/97 - Added code to remove Cypress Creek's flow value from the model
/* 02/05/97 - Removed Cypress Creek modification, replaced outflow with outflow
values
/*        computed from average measured water depths at transect locations
/*        that fall in the sill zone
/* 02/05/97 - Removed previous modification, however, used 0.5 of the measured
/*        flow value at the Suwannee station to pull water from the Back-sillz
/* 02/07/97 - Modified code to keep back-sillz from going negative, Removed
/*        previous modification.
/* 02/17/97 - Modified code again to keep back-sillz from going negative
/* 02/18/97 - Modified code again; removed 02/17/97 statement
/* 02/21/97 - Modified sill switch so that the outflow will not remove
/*        water below the sill gate threshold
/* 02/27/97 - Removed Sill Switch and Applied outflow to Stream-Zones Back-ups
/*        Located in back-ups directory
/* 02/28/97 - Implementation of correction factor for outflows used during high
/*        rainfall
/* 03/03/97 - Set outflow correction to 1.0
/* 03/04/97 - Adjusted precip-to-streams and precip-to-remove coefficients
/* 03/05/97 - Modified Stream Zones & therefore the precip-to-streams and
precip-to-remove
/*        were adjusted
/* 03/06/97 - Modified precip-to-streams and precip-to-streams variables
/* 03/06/97 - Implemented Sheet flow zone and removed precip-to-streams stuff
/* 03/10/97 - Adding adjustment for stream flow for high rainfall events
/* 03/24/97 - Getting back to basics: Water balance equation - remove outflow,
/*        northwest sheetflow, and stream zones.
/* 03/25/97 - Remove Outflow and redesigned the use of the northwest
/*        sheet flow zone to directly remove water from the swamp
/* 03/31/97 - Removed Sheet Flow Zone and Outflow Zone ... REMOVED ALL
OUTFLOW
/* 04/18/97 - Commented Code
/* 04/22/97 - Added Suwannee Outflow Zone
/**********************************************************************

&severity &warning &routine warning
&severity &error   &routine error

/* Perform Arc Commands First
```

```
/********************** Create Outflow and Pet Grids ********************

    /*Create PET Surface
/*    &type '        Creating PET Surface ...'
     &type %.suwannee-outflow-adj%
    /*Tin Point File
/*    &type '        Computing Tin & Lattice of PET Data ....'
/*    createtin %.temp%/tin%I%%j%%k%
/*    cover %.pet% point two-wk-pet-m # # year = %I% and month = %j% ~
/*    and interval = %k%
/*    end

    /* Find Mape of Refbnd
/*    &describe %.refbnd%
/*    &sv xmin = %dsc$xmin%; &sv ymin = %dsc$ymin%
/*    &sv xmax = %dsc$xmax%; &sv ymax = %dsc$ymax%

    /*Tin Lattice
/*    tinlattice %.temp%/tin%I%%j%%k% %.pet-prec-surfaces%/pet%I%%j%%k%
linear
/*    %xmin%, %ymin%
/*    %xmax%, %ymax%
/*    ~
/*    %.cellsize%
/*    ~
/*    kill %.temp%/tin%I%%j%%k% all

/******************** Create OUT H20 in Grid Env **************

/*check Program Env and Change to grid env
display 0
&if [show program] = ARC &then &do
grid
&end

/* Set Grid Analysis Env
/*setwindow %.refbnd%
/* setmask %.mask%
/*setcell %.cellsize%
/*setcell maxof

    /* Create outflow with relates.  The relate, flow.rel is stored in
    /* the grids directory set in hydro-model.aml.  This relate provides
```

```
/* access to outflow values stored in %.outflow%.pat. This variable is
/* set in hydro-model.aml.

 relate restore %.grids%/flow.rel
 /* Clear any selected items
 clearselect %.outflow%.pat info
 reselect %.outflow%.pat info year = %I% and month = %j% ~
                        and interval = %k% or zone = 0

 &type '        Creating Net Flow Surface ...'
 setwindow %.refbnd%

 /* PET is controlled differentially by period to modify the
 /* calculated PET values.  The three periods are: April-May, Oct-Nov
 /* little rain, high evap therefore, use percent-of-pet1;  June - Sept,
 /* high evap and high rain therefore use percent-of-pet2; Dec-March,
 /* average rain, little evap therefore, use percent-of-pet3

 &if %j% = 4 or %j% = 5 or %j% = 10 or %j% = 11 &then ~
         &sv PET-multiplier = %percent-of-pet1%
 &if %j% = 6 or %j% = 7 or %j% = 8 or %j% = 9 &then ~
         &sv PET-multiplier = %percent-of-pet2%
 &if %j% = 12 or %j% = 1 or %j% = 2 or %j% = 3 &then ~
         &sv PET-multiplier = %percent-of-pet3%

/**************************PRE-SILL CONDITION***********************/

 /*Switch for Pre-Sill and Post-sill Condition
 &if %I% < 1960 &then &do

    /* Use Pre-Sill Condition
    &type '       Pre-Sill Condition ....'

   %.temp%/net%I%%j%%k% = %.temp%/inh20%I%%j%%k% - ~
         (%.pet-prec-surfaces%/pet%I%%j%%k% * %PET-multiplier% *
%.grids%/veg-pet-coef) ~
         - %.grids%/suwan-outflow.outflow//depth-zone * %.suwannee-outflow-adj%

   /* Kill Intermediate Results
    &type '       Removing Intermediate Steps ...'
   kill %.temp%/inh20%I%%j%%k%

&end /*Pre-Sill Do loop
```

```
/*********************** POST SILL CONDITION ************************/

&else &do

    /*Use Post-Sill Condition
     &type '        Post-Sill Condition ....'
      &type %.suwannee-outflow-adj%
    %.temp%/net%I%%j%%k% = %.temp%/inh20%I%%j%%k% - ~
           (%.pet-prec-surfaces%/pet%I%%j%%k% * %PET-multiplier% *
%.grids%/veg-pet-coef) ~
           - (%.grids%/suwan-outflow.outflow//depth-zone *
%.suwannee-outflow-adj%)
     &type %.suwannee-outflow-adj%
    /* Kill Intermediate Results
    &type '        Removing Intermediate Steps ...'
    kill %.temp%/inh20%I%%j%%k%
&end /* End Do Loop for Post-Sill Condition

&return

/*Bail-out Routines

&routine warning
&severity &warning &ignore
&type A warning condition occurred in "Phase2.aml" of the Hydro Model. ...
&return &error Terminating program "Phase2.aml"

&routine error
&severity &error &fail
&type An Error has occurred in "Phase2.aml" of the Hydro Model. ...
&return &error Terminating program "Phase2.aml".
```

Phase3.aml

```
/* phase3.aml
/*********************************************************************
/*
/*   Phase3.aml computes the third phase of the hydro-model to create
/*   a surface called ewatxxx and dwatxxx where xxx specifies the year,
/*   month, and interval.  This is the computed ending water elevation
/*   and water depth for the specified period.
```

```
/*
/*    Called From: run-hydro-model.aml
/*    Calls: flowaccum.aml (moves water)
/*    Written by Nicholas Ansay & Cynthia S. Loftin
/*    Revised 04/18/97
/*
/*                  VARIABLE LIST
/*
/* percent-of-inflow    Percent of inflow water to move in inflow zones
/*               use roughness coefficients instead of percent-of-
/*               standing to determine how much water is to be moved.
/* pixels-to-move-water  Value used by flowaccum.aml. This value sets the
/*               distance a cell of water should move.
/* I, j,k          Counter Variables for year, month, interval name
/* .precip-100th-quartile Tracks the number of times a precip correction was
/*               used.  This is displayed when the model ends.
/* .temp           Location of temporary files.  This variable is set in
/*               Hydro-model.aml
/* .grids          Location of grids
/*
/*               GRIDS & COVERAGES
/*
/* toposurface       Current topo surface
/* amt%I%%j%%k%        Computed amount of water to move
/* inflow-zones      Grid that defines inflow zones
/* net%I%%j%%k%        Result from Phase 2 of the hydro model.  It
/*               defines the Net water that entered and left the
/*               swamp.
/* roughness500m      Grid of Mannings Coefficients or roughness coefficients
/*               based on a 1990 vegetation classification.
/* netslope          Grid that holds computed slope values derived from
/*               the net grid
/* tmp             Temporary grid
/* flowd%I%%j%%k%      Flow direction grid
/* moved-%I%%j%%k%     Moved water grid
/* tmpewat          Temporary end water grid
/* ewat%I%%j%%k%       Grid that holds the end water for a specific
/*               i,j,k.  This is one of the Results from Phase 3
/*               of the hydro model.
/* tmpdwat          Temporary depth of water
/* dwat%I%%j%%k%       Depth of water grid. This is a primary output of Phase3
/*
/*
```

```
/************************************************************************

&args I j k toposurface percent-of-inflow pixels-to-move-water

/******************** MODIFICATION LOG ******************************/
/*
/* 02/18/97 - Added code to zero out back-sillz for dwater if negative
/* 02/27/97 - Removed Stream Zones water movement code
/* 03/03/97 - Changed Precip Correction Value to 0.06
/* 03/03/97 - Moved a percentage of precip depth to stream zones
/* 03/05/97 - Set precip-correction to 0.0
/* 03/10/97 - Adding adjustment for streams for high rainfall events
/* 03/25/97 - Remove Outflow and redesigned the use of the northwest
/*         sheet flow zone to directly remove water from the swamp
/* 04/18/97 - Commented Code
/************************************************************************/
&severity &warning &routine warning
&severity &error   &routine error

/* About Moving Water:
/*
/* First, the amount of water to move is computed differentially.
/* If the cell is in an inflow zone, zone value > 0,
/* then the amount of water to move is "percent-of-inflow" of that value.
/* This is, in part, based on published values. In all other cells,
/* move water based on slope and roughness.
/*

&type '      Computing Amount of Water to Move With Roughness Grid...'

 %.temp%/netslope = sqrt(slope(%.temp%/net%I%%j%%k%, percentrise) / 100.0)
 %.temp%/amt%I%%j%%k% = con(%.grids%/inflow-zones > 0,
%.temp%/net%I%%j%%k% * ~
              %percent-of-inflow%, ~
              ((%.temp%/netslope * %.temp%/net%I%%j%%k%) ~
              / %.grids%/roughness500m))
 kill %.temp%/netslope

&type '      Computing Flow Direction ...'
    %.temp%/tmp = %.temp%/net%I%%j%%k% + %toposurface%
     %.temp%/flowd%I%%j%%k%  = flowdirection(%.temp%/tmp)

&type '      Moving Water in Open Areas ...'
```

```
    &r flowaccum %.temp%/flowd%I%%j%%k% %.temp%/amt%I%%j%%k% ~
           %.temp%/moved-%I%%j%%k% %pixels-to-move-water%

    %.temp%/tmpewat = %.temp%/net%I%%j%%k% + %toposurface% - ~
                  %.temp%/amt%I%%j%%k% + %.temp%/moved-%I%%j%%k%

    %.temp%/ewat%I%%j%%k% = focalmean(%.temp%/tmpewat, rectangle,5,5)


&type '       Computing Depth of Water ...'
%.temp%/dwat%I%%j%%k% =  con(%.temp%/ewat%I%%j%%k% - %toposurface% <
0, 0,~
                  %.temp%/ewat%I%%j%%k% - %toposurface%)

/* Set Endwater to startwater variable
&sv .startwl = %.temp%/dwat%I%%j%%k%

&type '       Removing Intermediate Results ...'
    /* Kill  %.temp%/amt%I%%j%%k%
    /* kill %.temp%/net%I%%j%%k%
    /*kill %.temp%/moved-%I%%j%%k%
    Kill %.temp%/flowd%I%%j%%k%
    kill %.temp%/tmp
    kill %.temp%/tmpewat

/* quit /* Quit grid env

&return

/*Bail-out Routines

&routine warning
&severity &warning &fail
&type A warning condition occurred in "Phase3.aml" of the Hydro Model. ...
&return  &error Terminating program "Phase3.aml".

&routine error
&severity &error &fail
&type An Error has occurred in "Phase3.aml" of the Hydro Model. ...
&return &error Terminating program "Phase3.aml".
```

<u>Flowaccum.aml</u>

```
/* flowaccum.aml
/*************************************************************
/*
/*  Flowaccum.aml takes as input flow-direction, and amount of
/*  water to move and moves the water.
/*
/*
/*  Calls:
/*  Called From: Phase3.aml of the hydro model
/*  and it returns a moved water grid.
/*
/*  Written by Nicholas Ansay and Cynthia S. Loftin
/*  Revised 10/28/96
/*
/*                VARIABLE LIST
/*
/* flow-dir          Holds the path to the flow direction grid
/* amt-to-move          Holds the path to the amount of water to move
/* moved             Result of the aml "Moved water"
/* pixels-to-move-water   Number of pixels to move water
/* I                Loop counter
/*
/*                GRIDS & COVERAGES
/*
/* p
/* p-total1 - 8
/*************************************************************

&args flow-dir amt-to-move moved pixels-to-move-water

&severity &warning &routine warning
&severity &error   &routine error

&do I = 1 &to %pixels-to-move-water% &by 1

DOCELL

P := 0

p  := %flow-dir%(-1,-1)

p-total1 := con( p == 2, %amt-to-move%(-1,-1),0)
```

```
p := %flow-dir%(0,-1)
p-total2 := con(p == 4,%amt-to-move%(0,-1),0)

p := %flow-dir%(1,-1)
p-total3 := con( p == 8,%amt-to-move%(1,-1),0)

p := %flow-dir%(1,0)
p-total4 := con(p == 16,%amt-to-move%(1,0),0)

p := %flow-dir%(1,1)
p-total5 := con( p == 32,%amt-to-move%(1,1),0)

p := %flow-dir%(0,1)
p-total6 := con(p == 64,%amt-to-move%(0,1),0)

p := %flow-dir%(-1,1)
p-total7 := con( p == 128,%amt-to-move%(-1,1),0)

p := %flow-dir%(-1,0)
p-total8 := con(p == 1,%amt-to-move%(-1,0),0)

temp-grid := p-total1 + p-total2 + p-total3 + p-total4 + p-total5 ~
             + p-total6 + p-total7 + p-total8

%.temp%/moved%I% = con(isnull(temp-grid),0,temp-grid)

&type %.temp%/moved%I%

END

/* Set amt-to-move variable to the latest Moved Water Grid
&sv amt-to-move = %.temp%/moved%I%

&end

%moved% = %amt-to-move%

&do I = 1 &to %pixels-to-move-water% &by 1

kill %.temp%/moved%I%

&end
```

```
&return

&routine warning
&severity &warning &fail
&type A warning condition occurred in "Flowaccum.aml" of the Hydro Model. ...
&return  &error Terminating program "Flowaccum.aml".

&routine error
&severity &error &fail
&type An Error has occurred in "Flowaccum.aml" of the Hydro Model. ...
&return &error Terminating program "Flowaccum.aml".
```

Display.menu

```
/****************************************************
/*
/*
/*
/*        Display Surface AML
/*        Written by Nicholas Ansay
/*
/*
/****************************************************

&args shadegrid

mape %shadegrid%

gridpaint %shadegrid% # linear # gray

&return
```

Display.aml

```
/* display.aml
/********************************************************
/*
/*   Display.aml is called by Hydro-model.menu. It
/*   prepares the Arcplot environment and runs Display.menu
/*   which allows the user to display and query endwater grids
```

```
/*   created by the hydro-model.
/*
/*   Written by Nicholas J. Ansay and Cynthia S. Loftin
/*   Revised: 4/21/97
/***************************************************************

&severity &warning &routine warning
&severity &error   &routine error

&thread &delete HYDRO

/* Check program Environment
&if [locase[show program]] = arc &then &do
display 9999 3  position uc
arcplot
shadeset color.shd
&end

&if [locase[show program]] = grid &then &do
quit /* quit grid env
display 9999 3 position uc
arcplot
shadeset color.shd
&end

&menu display.menu ~
&position &ur &stripe 'Display & Analyize Results'

&call finish-up

&return /* End display.aml

&routine finish-up

&if [show program] = ARCPLOT &then quit
&thread &create HYDRO-AML &r hydro-model.aml
&return

/*Bail-out Routines

&routine warning
&severity &warning &ignore
&type A warning condition occurred in "Display.aml" of the Hydro Model. ...
```

```
&call finish-up

&return &error

&routine error
&severity &error &fail
&type An Error has occurred in "Display.aml" of the Hydro Model. ...
&call finish-up
&return &error
```

Shade-surfaces.menu

```
/* shade-surfaces.menu
/* ******************************************************
/*
/*
/*      Shade-surfaces.menu is called by display.menu.
/*      It allows the user to select a surface, shade it,
/*      and check cell values.  The menu calls shade-surface.aml
/*      and passes to it the following variables or surfaces:
/*
/*      surface    Surface select from a menu.
/*      shadeset   Shade set selected by user.
/*
/*      Directory and Shade or create a profile.
/*      Written by Nicholas J. Ansay & Cynthia S. Loftin
/*      Revised 04/21/97
/*
/* ********************************************************

Current Surface:
%cursurface

Select Surface:
%selectsurface
          %button4

          %button5

Select Remap Table
-----------------
```

```
%shadeset

   %clear   %arcplot  %cancel

%cursurface DISPLAY surface 45 VALUE

%selectsurface INPUT surface 20 TYPEIN NO SCROLL YES ROWS 4 ~
 REQUIRED GRID  %.temp%/* -SORT

%clear BUTTON 'Clear Canvas' clear

%button4 BUTTON  'Shade Grid' &r shade-surface.aml %surface% %shadeset%
%button5 BUTTON  'Cellvalue' cellvalue %surface% *
%shadeset CHOICE shadeset PAIRS INITIAL ewat.remap 'End Water' ~
        ewat.remap 'Water Depth' dwat.remap 'Linear' linear
%arcplot BUTTON 'AP Prompt' &tty

%cancel BUTTON CANCEL 'CANCEL' &return

%FORMOPT SETVARIABLES IMMEDIATE MESSAGEVARIABLE msg
```

Movie.menu

```
/* movie.menu
/* ******************************************************
/*
/*
/*      Movie.menu is called by display.aml and it runs
/*      "run-movie.aml".  It allows the user to enter a
/*      range of dates. It then runs run-movie.aml which
/*      creates a movie of End Water surfaces for those intervals.
/*      Written by Nicholas J. Ansay & Cynthia S. Loftin
/*      Revised 04/21/97
/*
/*              Variables:
/* bmonth, byear   Beginning Month and Year
/* emonth, eyear   Ending Month and Year
/*
/* *******************************************************

   Enter Interval
```

```
        Month    ^Year
 Begining:  %bmonth %byear
 Ending:    %emonth %eyear

    %apply
   %clear   %arcplot  %cancel

%bmonth INPUT BMONTH 7 TYPEIN YES SCROLL NO ~
 REQUIRED ~
 HELP 'Begining Month' ~
 NEXT %byear ~
 INITIAL '6' ~
 RANGE 1 12 ~
 INTEGER
%byear INPUT BYEAR 7 TYPEIN YES SCROLL NO ~
 REQUIRED ~
 HELP 'Begining Year' ~
 NEXT %emonth ~
 INITIAL '1980' ~
 RANGE 1930 1993 ~
 INTEGER
%emonth INPUT EMONTH 7 TYPEIN YES SCROLL NO ~
 REQUIRED ~
 HELP 'Ending Month' ~
 NEXT %eyear ~
 INITIAL '12' ~
 RANGE 1 12 ~
 INTEGER
%eyear INPUT EYEAR 7 TYPEIN YES SCROLL NO ~
 REQUIRED ~
 HELP 'Ending Year' ~
 INITIAL '1980' ~
 RANGE 1930 1993 ~
 INTEGER

%apply BUTTON 'APPLY' ~
  &r run-movie.aml %bmonth% %byear% %emonth% %eyear%

%cancel BUTTON CANCEL 'CANCEL' &return

%clear BUTTON 'Clear Canvas' clear

%arcplot BUTTON 'AP Prompt' &tty
```

%FORMOPT SETVARIABLES IMMEDIATE MESSAGEVARIABLE msg

Check-stations.aml

```
/*----------------------------AUTHOR-------------------------------
/*
/*Original Coding:   ESRI  & Nicholas J. Ansay
/*              Revised 4/21/97
/*
/*-----------------------------NAME--------------------------------
/*
/*Check-station.AML
/*Copyright 1995, Environmental Systems Research Institute, Inc.
/*
/*---------------------------PURPOSE-------------------------------
/*
/* This AML creates an Ascii file in the form of Date, id, end
/* water elevation, depth of water, and station name.  Cell values for end
/* water and depth of water are recorded at all point locations in ptcov.
/* Cell values are captured with the CELLVALUE and &watch command.
/* The &watch file is opened and the elevation data is extracted then written
/* to out-put-file.
/*
/*----------------------------USAGE--------------------------------
/*
/* CHECK-STATIONS <ewat> <dwat> <point_cover> <out-put-file><Begin Month> ~
/*        <Begin Year> <End Month> <End Year>
/*
/*--------------------------VARIABLES------------------------------
/*
/*                      Local variables:
/*
/* ewat         Root Name of ewat grids to take cell values from.  Date is used
/*          as a suffix to identify the grid
/* dwat      Root Name of dwat grids to take cell values from.  Date is used
/*          as a suffix to identify the grid
/* ptcov        Name of point coverage to which cell values are added
/* old$messages       Save setting of &messages
/* old$display Save setting of DISPLAY
/* old$echo     Save setting of &echo
/* record       One line read from watch file
```

```
/* out-put-file Output of aml.  This file contains the Date, ID, end water
/*           elevation, water depth, and station name
/* spot-item    Value at point xy location
/* bmonth byear Begining Month and Year
/* emonth eyear Ending Month and Year
/*
/*
/**********************************************************************

&severity &error &routine bailout

&args ewat dwat ptcov out-put-file bmonth byear emonth eyear

&if [show &thread &exists HYDRO] &then &thread &delete HYDRO
&if [show &thread &exists CHECK-STATIONS] &then &thread &delete
CHECK-STATIONS

/* -----------Argument checking----------------

&if [show program] ne 'ARC' &then
 &return This aml must be run from ARC

&if [null %ewat%] &then
 &return Usage: CHECK-STATIONS <ewat> <dwat> ~
 <point_coverage> <output-file>~
 <Begin Month> <Begin Year> <End Month> <End Year>

&if [null %ptcov%] &then
 &return Usage: CHECK-STATIONS <ewat> <dwat> ~
 <point_coverage> <output-file> ~
 <Begin Month> <Begin Year> <End Month> <End Year>

&if ^ [exists %ptcov% -point] &then
 &return Point coverage %ptcov% does not exist

&if [exists %out-put-file% -file] &then &do
 &type File %out-put-file% Exists.
 &call exit
 &return
 &end


/* Now go into Arcplot and get the values
```

```
&sv old$display [show display]
display 9999 1   /* A graphic display is needed
ap

/* Open output file
&sv output-fileunit = [open %out-put-file%tmp output-filestat -write]

/* Loop Through Grids by Year, get cellvalue at each End Water Check Station,
/* Capture it with &watch, Read it and write it to a file with the date, station
/* ID, and the computed elevation.

&do  I = %byear% &to %eyear% &by 1

   &do j = %bmonth% &to 12 &by 1
     &type
&type **************** Processing Year %I% Month %j% ********************
     &type
     &type
     /*do loop for interval
        &do k = 1 &to 2 &by 1
&if ^ [exists %ewat%%I%%j%%k% -grid] &then &do
 &type Grid %ewat%%I%%j%%k% does not exist
 &call exit
 &return
 &end
mape %ewat%%I%%j%%k%

/* Do not alter the lines below. This AML depends on capturing screen
/* messages to a watch file.

&s old$echo [show &echo]
&echo &off
&s old$messages [show &messages]
&messages &on

/* Start a loop to go through the PAT, find the cell value at each
/* point location, and write it to an Ascii File.
/* Declare and open a cursor to read and write to the PAT

cursor ptcur declare %ptcov% points ro
cursor ptcur open

&do &while %:ptcur.aml$next%
```

```
 &s old$echo [show &echo]
 &echo &off
 &s old$messages [show &messages]
 &messages &on

 /* Start the watch file, get a point, and get the value w/ cellvalue.

 &watch xxtemp
 cellvalue %ewat%%I%%j%%k% [show select %ptcov% point 1 xy]
 cellvalue %dwat%%I%%j%%k% [show select %ptcov% point 1 xy]
 &watch &off

 &echo %old$echo%

 /* Open the watch file and read from it

 &s file$unit1 [open xxtemp openstat$unit1 -r]
 &s record-ewat [read %file$unit1% readstat$unit1]
 &s record-dwat [read %file$unit1% readstat$unit1]

 /* Extract the last element, it's the cell value
 /* and set %spot-item-ewat% and %spot-item-dwat% to that value
 /* If the location has NODATA, set %spot-item% to -9999

 &if [keyword NODATA [unquote %record-ewat%]] = 0 &then &do/* The cell is not
NODATA
   &s spot-item-ewat [extract 9  [unquote %record-ewat%]]
   &s spot-item-dwat [extract 9  [unquote %record-dwat%]]
   &end
 &else
   &goto Skip    /* The cell has NODATA
   &sv id = %:ptcur.id%
   &sv station = %:ptcur.station%
   &sv out-record = [quote %I% %j% %k% %id% %spot-item-ewat%
%spot-item-dwat% %station%]
   &sv write-stat = [write %output-fileunit% %out-record%]

&label Skip
 &s close$stat [close %file$unit1%]
 cursor ptcur next

&end
 cursor ptcur remove
```

```
    &end /* End interval loop

   &if %j% = %emonth% and %I% = %eyear% &then &goto finished
  &end  /* End month loop
   &sv bmonth = 1

 &end /* End Year Loop

 &goto finished

/*
/* -------------------------- Finish ------------------------------
/*
&label finished
&if [variable old$display] &then
  display %old$display%
&if [variable old$messages] &then
  &messages %old$messages%
&if [variable old$echo] &then
  &echo %old$echo%
&s close$stat [close -all]

/* Concatenate Summary.dat with the output from this aml
&if [exists %.hydro-model-home%/summary.dat -file] &then &do
   &sys cat %.hydro-model-home%/summary.dat %out-put-file%tmp > %out-put-file%
   &sys \rm %out-put-file%tmp
   &end

&sv d [delete xxtemp -file]
&if [show program] = ARCPLOT &then q     /* quit from arcplot
&thread &create HYDRO-AML &r hydro-model.aml
&return
/*
/* ------------------------- Routine Bailout ----------------------------
/*
&routine bailout
&severity &error &ignore
&call exit
&return; &return &error Bailing out of check-station.aml

/* -------------------------Routine Exit ---------------------
&routine exit
```

```
&if [variable old$display] &then
 display %old$display%
&if [variable old$messages] &then
 &messages %old$messages%
&if [variable old$echo] &then
 &echo %old$echo%
&s close$stat [close -all]
&sv d [delete xxtemp -file]
&if [show program] = ARCPLOT &then q    /* quit from arcplot
&thread &create HYDRO-AML &r hydro-model.aml
&return
```

Shade-surfaces.aml

```
/* Shade-surfaces.aml
/*************************************************************
/*
/*    Shade-surfaces.aml is called by shade-surfaces.menu.
/*    This aml runs the gridpaint commands using a user specified
/*    shadeset.
/*
/*    Written by Nicholas J. Ansay and Cynthia S. Loftin
/*    Revised 04/21/97
/*
/*************************************************************

&args surface shadeset
mape %surface%

clear

&if %shadeset% = linear &then gridpaint %surface% # linear nowrap gray

&if %shadeset% = ewat.remap &then &do
gridshades %surface% # %.map-tools%/%shadeset% nowrap
shadeset color.shd
keyposition 8.3 8.3
keyseparation .15 .25
keybox .5 .25
keyshade %.map-tools%/ewat.key
&end
```

```
&if %shadeset% = dwat.remap &then gridshades %surface% #
%.map-tools%/%shadeset% nowrap

     /* Display coverages for reference
     arcs %.coverages%/refbnd
     linecolor red
     linesymbol 5
     arcs %.coverages%/fir-isld
     arcs %.coverages%/sill
     linecolor white
     points %.checkstations%
     textcolor red
     pointtext %.checkstations% station # cr
     textcolor white

&return
```

Run-movie.aml

```
/* Run-movie.aml
/*************************************************************
/*
/*    Run-movie.aml displays the first interval of each
/*    month using a selected remap table.
/*    Movie.menu passes the beginning date and month,
/*    and ending date and month.  Run-movie.aml displays
/*    each endwater grid in succession.
/*
/*    Called From: Movie.menu
/*    Calls:
/*
/*    Written by Nicholas J. Ansay and Cynthia S. Loftin
/*    Revised 10/29/96
/*
/*             VARIABLES
/*
/* bmonth byear    Begining Month and Year (Used to start the movie)
/* emonth eyear    Ending Month and Year  (Used to end the movie)
/* bmonth2         A working copy of bmonth.  Used in routine file-exist
/* I, j,           Year and Month counters
/* .map-tools      Location of remap tables and key shades
/* .coverages      Location of coverages used by the model
```

```
/* .temp          Temporary storage location of all results
/* .checkstations   Location of point coverage used to check the
/*              results of the hydro model
/*
/*                  GRIDS, COVERAGES, FILES
/*
/* ewat.key        A key shade file used to display a legend.
/* ewat.remap      A remap table used to color end water grids
/* ewat%I%%j%1     The first end water for the year I and month j
/* refbnd          Arc coverage that defines the refuge boundary
/* fir-isld        Polygon coverage of refuge islands that have
/*                 fire compartments
/* sill            Arc coverage defining the sill
/*
/**************************************************************

&args bmonth byear emonth eyear

&severity &warning &routine warning
&severity &error   &routine error

/* Check if grids for range of dates exists
&call file-exist

/* Set Arcplot Env
clear
shadeset color.shd
keyposition 8.3 8.3
keyseparation .15 .25
keybox .5 .25
textcolor white
keyshade %.map-tools%/ewat.key
textset font.txt
textsymbol 14
markersymbol 2
markersize .2

&do  I = %byear% &to %eyear% &by 1

  &do j = %bmonth% &to 12 &by 1

    &type Processing Year: %I% Month: %j%
    move 8.2 1.5
```

```
    textcolor white
    &sv string = [quote Processing Year %I%: Month %j%]
    text %string%

    gridpaint %.temp%/ewat%I%%j%1 # %.map-tools%/ewat.remap
    arcs %.coverages%/refbnd
    linecolor red
    linesymbol 5
    arcs %.coverages%/fir-isld
    arcs %.coverages%/sill
    linecolor white
    points %.checkstations%
    textcolor red
    pointtext %.checkstations% station # cr
    patch 8.12 1.99 11.9 2.26

  &if %j% = %emonth% and %I% = %eyear% &then &goto FINISHED
  &end  /* End month loop

  &sv bmonth = 1

&end /* End Year Loop

&label FINISHED
&call finish-up

&return /* end Movie.aml

&routine file-exist
&sv bmonth2 = %bmonth%
&do  I = %byear% &to %eyear% &by 1
  &do j = %bmonth2% &to 12 &by 1
  &if ^ [exists %.temp%/ewat%I%%j%1 -grid] &then &do
    &popup %.messages%/file-doesnt-exist.txt 8 50 3 2
    &call error
    &end /* End Do

  &if %j% = %emonth% and %I% = %eyear% &then &goto DONE-WITH-CHECKS
  &end  /* End month loop
  &sv bmonth2 = 1

&end /* End Year Loop
```

```
&label DONE-WITH-CHECKS
mape %.temp%/ewat%I%%j%1
&return

*Bail-out Routines

&routine warning
&severity &warning &fail
&type A warning condition occurred.
&call finish-up
&return

&routine error
&severity &error &fail
&type An Error has occurred in "Run-moviel.aml" of the Hydro Model. ...
&call finish-up
&return &error

&routine finish-up

&return
```

Trash-results.aml

```
/* trash-results.aml
/******************************************************************
/*
/*    Trash-results.aml deletes all files in the tmp
/*    directory.
/*
/*    Called From: Hydro-model.menu
/*    Calls: Programstatus.menu
/*
/*    Revised 11/06/96
/*    Written by Nicholas J. Ansay & Cynthia S. Loftin
/*
/*****************************************************************

&severity &warning &routine warning
&severity &error   &routine error

&sv .programstatus = 'Files are being deleted!'
```

```
&sv choice = [getchoice YES NO -Prompt 'Do you really want to do this?']

&if %choice% = YES &the &do
 &thread &create STATUS &m programstatus.menu &position &below &thread
HYDRO &size 200 150 &stripe 'Program Status'
 &thread &synchronize STATUS
 deleteworkspace %.temp%
 Y
 ~
 createworkspace %.temp%
 &thread &delete STATUS
 &end /* End Do

&return

/*Bail-out Routines

&routine warning
&severity &warning &fail
&type A warning condition occurred in "Trash-results.aml" of the Hydro Model. ...
&return  &error Terminating program "Trash-results.aml".


&routine error
&severity &error &fail
&type An Error has occurred in "Trash-results.aml" of the Hydro Model. ...
&return &error Terminating program "Trash-results.aml".
```

APPENDIX C
VEGETATION TRANSECT LOCATIONS

Transect	UTM X	UTM Y	Transect Length (m)	Number of Sample Points
1	387702	3400448	35	13
2	386615	3397585	31	11
3	387868	3399466	39	14
4	386248	3400033	21	9
5	386889	3398695	38	9
6	386883	3398287	33	12
7	387804	3400514	90	18
8	387880	3398755	90	15
9	387586	3396935	96	18
10	386240	3395901	68	15
11	386446	3398946	79	16
12	386111	3399945	60	12
13	388148	3399369	74	15
14	387248	3396662	38	15
15	385695	3396800	42	14
16	386847	3399062	32	12
17	389962	3421187	106	20
18	389541	3421512	30	8
19	390668	3420888	98	17

Transect	UTM X	UTM Y	Transect Length (m)	Number of Sample Points
20	390391	3418509	46	14
21	390764	3417308	82	19
22	390631	3419899	69	15
23	390573	3419384	101	15
24	390479	3418106	48	17
25	390470	3419319	31	11
26	389354	3417990	50	12
27	390739	3416323	62	11
28	390738	3416319	53	12
29	390175	3419109	69	12
30	390090	3416658	73	9
31	389190	3416413	51	12
32	390646	3416718	119	11
33	376579	3415982	88	14
34	375950	3415522	111	15
35	376641	3415607	70	11
36	377092	3416063	46	12
37	378630	3416993	73	15
38	378013	3415222	102	8
39	378165	3415028	103	12
40	378124	3416613	37	12
41	377117	3418840	55	9
42	377157	3416975	49	12
43	378107	3416953	45	13
44	378043	3415905	75	16

Transect	UTM X	UTM Y	Transect Length (m)	Number of Sample Points
45	377288	3416588	41	12
46	375546	3416153	35	11
47	375849	3415900	70	14
48	377129	3417528	46	9
49	364645	3407945	120	10
50	366036	3409035	107	9
51	364887	3408995	95	13
52	364528	3410441	102	5
53	365014	3409039	135	12
54	364702	3407691	88	9
55	363939	3411780	102	5
56	364478	3414438	28	9
57	364340	3412611	96	10
58	366273	3410523	46	6
59	365513	3410479	45	6
60	363714	3407625	212	8
61	364347	3411736	57	9
62	364912	3410368	73	9
63	367545	3409956	102	5
64	379194	3431737	78	12
65	379521	3432106	54	11
66	379499	3432402	58	9
67	378678	3432449	57	12
68	378653	3432829	78	12
69	377409	3432009	72	12

Transect	UTM X	UTM Y	Transect Length (m)	Number of Sample Points
70	376946	3432264	59	12
71	376694	3431783	56	12
72	377016	3431221	54	9
73	377458	3431621	101	9
74	377912	3430790	103	18
75	378070	3430364	43	9
76	377220	3430298	48	12
77	376908	3430650	78	14
78	377706	3429703	42	12
79	377215	3429728	58	12
80	365204	3407501	102	5

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BIOGRAPHICAL SKETCH

Cynthia Rohrer Smith was born in Worcester, Massachusetts, on 8 October 1962. She grew up in Vienna, Virginia, after having resided briefly in Massachusetts, South Carolina, and Ohio. In 1984 she earned a Bachelor of Arts degree in biology from the University of Virginia. Following summer employment with the U.S. Fish and Wildlife Service (USFWS), she began graduate studies at Auburn University. Her thesis researched eastern indigo snake (*Drymarchon corais couperi*) ecology in North Florida. In 1987, she received her Master of Science degree in wildlife management and began employment as a biologist with the USFWS-National Wetlands Research Center in Corpus Christi, Texas. She married James Lee Loftin in 1988 and changed her name to Cynthia Smith Loftin. After studying wintering waterfowl and seagrass ecology in the Laguna Madre, Texas, she began a doctoral program in 1991 at the University of Florida in the Department of Wildlife Ecology and Conservation. Her dissertation research was conducted during 1991-1997, with a brief hiatus for the birth of her son, Steven Avery Loftin, in 1996. While conducting her research, she served the Okefenokee Swamp National Wildlife Refuge as a consulting ecologist and hydrologist and assisted with preparation of the Environmental Assessment on the future management of the Suwannee River sill. In 1998 she received an award of appreciation for this effort.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Wiley M. Kitchens

Wiley M. Kitchens, Chair
Associate Professor of Wildlife
Ecology and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

George W. Tanner

George W. Tanner
Professor of Wildlife Ecology
and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Loukas G. Arvanitis

Loukas G. Arvanitis
Professor of Forest Resources
and Conservation

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ramon C. Littell

Ramòn C. Littell
Professor of Statistics

This dissertation was submitted to the Graduate Faculty of the College of Agriculture, and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

December, 1998

Rachel B. Shireman

Dean, College of Agriculture

Dean, Graduate School